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# **ANEXO I**

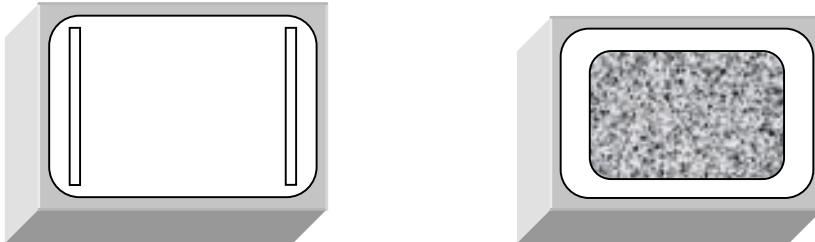
## ANEXO I

Calibração da bomba de diafragma OMEL NSP-II

Nº visor	Tempo 1L (min)	Q (L/h)	V <sub>fc</sub> <sup>*</sup> (m/s)	Re	regime
3	22	2,7	0,010	3,96*10	LAMINAR
4	8	7,5	0,030	1,08*10 <sup>2</sup>	LAMINAR
5	5,2	11,4	0,046	1,65*10 <sup>2</sup>	LAMINAR
6	3,5	17,1	0,068	2,44*10 <sup>2</sup>	LAMINAR
7	2,7	22,5	0,090	3,24*10 <sup>2</sup>	LAMINAR
8	2	30,0	0,120	4,31*10 <sup>2</sup>	LAMINAR
9	1,7	36,0	0,140	5,03*10 <sup>2</sup>	LAMINAR
10	1,5	40,0	0,160	5,75*10 <sup>2</sup>	LAMINAR

\* velocidade de fluxo cruzado

Dimensões do módulo 1 (retangular pequeno)



Dimensões do canal de alimentação

Largura = c = 42,0 mm = 0,04200 m

Espessura = b = 3 mm = 0,003m

Altura = h = 1,65 mm = 0,00165 m

Área de seção perpendicular ao fluxo cruzado = Acf = c.h = 7,0 \*10<sup>-5</sup>

Área efetiva de membrana = 6,3 \* 12,3 cm

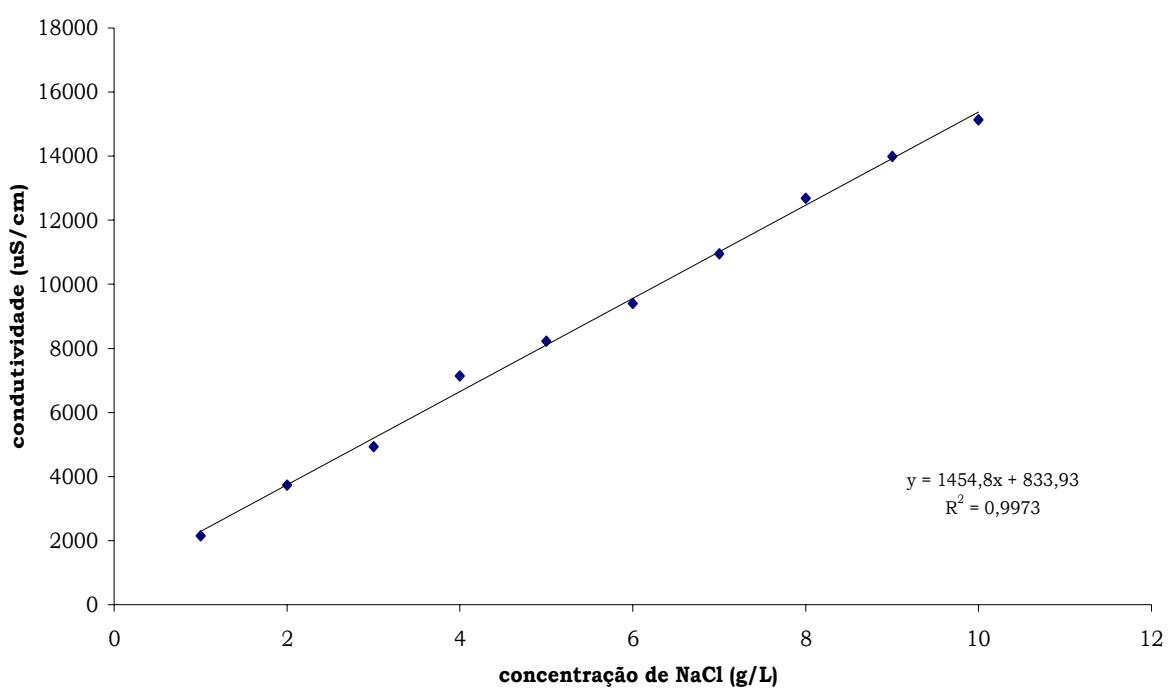
Calibração do condutivímetro QUIMIS modelo Q-450

Solução: NaCl

Temperatura ambiente: 28,2 °C

<b>NaCl (g/L)</b>	<b>Condutividade (μS/cm)</b>
1	2152
2	3727
3	4934
4	7141
5	8230
6	9405
7	10957
8	12685
9	13986
10	15135

**Curva de calibração condutivímetro Digimed  
NaCl**

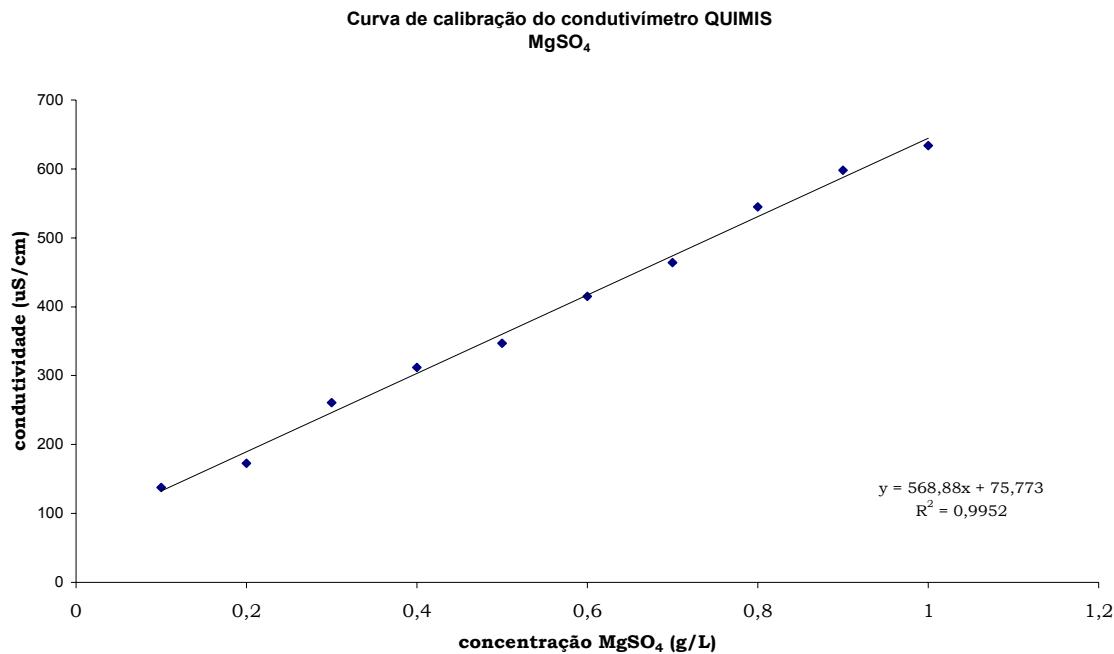


Calibração do condutivímetro QUIMIS modelo Q-450

Solução: MgSO<sub>4</sub>

Temperatura ambiente: 26,8 °C

<b>NaCl (g/L)</b>	<b>Condutividade (µS/cm)</b>
0,1	138
0,2	173
0,3	261
0,4	312
0,5	347
0,6	415
0,7	464
0,8	545
0,9	598
1	634
2	1120
3	1618
4	2119
5	2486
6	2870
7	3280
8	3574



# **ANEXO II**

## ANEXO II

Tabela 1 - Codificação dos experimentos desenvolvidos no decorrer da etapa experimental do trabalho de Tese

Nº	Membrana utilizada	Solução de alimentação	Tempo
01	TFC-SR	CaSO <sub>4</sub> (4000 mg/L)	2 dias
02	NF-90-400	CaSO <sub>4</sub> (4000 mg/L)	2 dias
03	NF-90-400	Água do mar ASTM sem MP*	2 dias
04	NF-90-400	NaCl (30, 300, 3000 mg/L)	4 dias
05	NF-90-400	Água do mar ASTM sem MP	7 dias
06	TFC-SR	CaSO <sub>4</sub> (4000 mg/L)	4 dias
07	NF-90-400	MgSO <sub>4</sub> (1,65 g/L)	10 dias
08	NF-90-400	MgSO <sub>4</sub> (1,65 g/L)	10 dias
09	NF-90-400	MgSO <sub>4</sub> (3000 mg/L)	10 dias
10	NF-90-400	MgSO <sub>4</sub> (4000 mg/L)	10 dias
11	NF-90-400	CaSO <sub>4</sub> (4000 mg/L)	3 dias
12	NF-90-400	Água do mar ASTM sem MP	10 dias
13	NF-90-400	Na <sub>2</sub> SO <sub>4</sub> ( 4000 mg/L)	10 dias
1	NF-90-400	K <sub>2</sub> SO <sub>4</sub> (4000 mg/L)	10 dias
15	NF-90-400	MgSO <sub>4</sub> (3000 mg/L) + NaCl (3000 mg/L)	10 dias
16	NF-90-400	K <sub>2</sub> SO <sub>4</sub> (4000 mg/L) +NaCl (4000 mg/L)	10 dias
17	NF-90-400	Na <sub>2</sub> SO <sub>4</sub> (4000 mg/L) +NaCl (24,53 g/L)	10 dias
18	NF-90-400	K <sub>2</sub> SO <sub>4</sub> (4000 mg/L) +NaCl (24,53 g/L)	10 dias
19	NF-90-400	MgSO <sub>4</sub> (4000 mg/L) +NaCl (24,53 g/L)	10 dias
20	NF-90-400	CaSO <sub>4</sub> (1,26 g/L) +NaCl (24,53 g/L)	10 dias
21	NF-90-400	Água do mar **	10 dias
22	NF-90-400	Água do mar**	10 dias

Para analisar os dados obtidos nos experimentos e entender os resultados é necessário conhecer alguns parâmetros que influenciam de forma direta os fenômenos envolvidos no processo de separação por membranas, mais especificamente a nanofiltração.

➤ Com relação a rejeição:

É importante conhecer as concentrações das correntes de alimentação e permeado para saber o potencial de rejeição da membrana. Para quantificar os íons presentes nas duas correntes citadas utilizamos a técnica de cromatografia iônica, com ela foi possível saber a quantidade de íons cloreto e sulfato antes e após a nanofiltração.

Nas soluções simples o acompanhamento foi feito com auxílio de condutivímetro, porém nas soluções multicomponentes a quantificação foi feita apenas por cromatografia.

Com o resultado de concentração das correntes a rejeição da membrana foi calculada pela fórmula:

$$R\% = \frac{(C_o - C_p)}{C_o} * 100$$

onde:

$C_o$  = concentração alimentação

$C_p$  = concentração permeado

➤ Com relação ao fluxo:

Os custos de operações nos processos que utilizam membranas estão diretamente relacionados com o fluxo permeado. Quando se é possível mover mais água através da membrana por unidade de área por tempo menos área de membrana é requerida para atingir o fluxo projetado. Isso resulta em menor custo com módulos de membranas, periféricos, equipamentos de monitoração.

O acompanhamento da queda de fluxo permeado foi feito utilizando-se rotâmetro, a cada período, pré estabelecido, o fluxo permeado era desviado do tanque para o instrumento e a medição era feita, ao final a corrente era encaminhada para o local de origem.

Foi feita uma tentativa de acompanhamento do fluxo através da variação de massa ao longo do experimento, em decorrência de limitações operacionais a idéia foi descartada.

Com os valores de  $\Delta t/mL$  calcula-se o fluxo por tempo e por área de membrana:

$$J_p = \frac{V_p}{t * A}$$

onde :

$V_p$  = volume de permeado

$t$  = tempo

$A = 77,49 \text{ cm}^2$

O fluxo de água limpa através da membrana sem material depositado em sua superfície ou poros, é descrito pela lei de Darcy:

Diferença de pressão transmembrana

$$J = \frac{\Delta P}{\mu R_m}$$

Resistência hidráulica

Viscosidade  
absoluta da  
água

Essa equação é similar (em termos de forma) a equação de Kedem-Katchalsky, se o fluxo permeado (água) é muito maior que o fluxo de soluto (como em uma solução diluída), então:

$$J_a L_v (\Delta p - \sigma \Delta \pi)$$

- Com relação a transferência de massa

O valor do coeficiente de transferência de massa ( $k$ ) é de fundamental importância e pode ser calculado através de correlações empíricas. Nessas correlações, o coeficiente de transferência de massa, expresso pelo número de Sherwood (Sh), é uma função dos números adimensionais de Reynolds (Re) e Schmidt (Sc). O número de Sh pode ser interpretado como o gradiente de concentração adimensional na superfície da membrana. O número de Re, por sua vez, relaciona as

forças de inércia e viscosas e o número de Sc relaciona a difusividade de momento e de massa (Incropora, 2002).

$$Sh = \frac{k * d_h}{D} = a * Re^b * Sc^c$$

$$Re = \frac{d_h * v}{\nu} = \frac{\rho * v * d_h}{\eta}$$

$$Sc = \frac{\nu}{D}$$

Para regime laminar:

$$1,85 * \left( \frac{Re * Sc * d_h}{L} \right)^{0,33}$$

Outra correlação empírica importante utilizada no estudo foi o número de Peclet, esse número caracteriza o balanço entre convecção e difusão na camada limite, ou seja, conhecendo-se o número de Peclet é possível estimar o comportamento da polarização de concentração.

$$Pe = \frac{J_v \delta}{D}$$

As conclusões deste trabalho foram tiradas com base em valores calculados através dos modelos supra citados e ainda, quando necessário, modelos descritos no capítulo Modelos matemáticos.

# **ANEXO III**

### **ANEXO III**

O Cromatógrafo de íons fornece um relatório como o que se encontra nesta seção porém por motivo de tamanho os resultados foram organizados em tabelas.

#### **Experimento 01**

**Solução:** CaSO<sub>4</sub> 4000 mg/L (CaCl<sub>2</sub> + Na<sub>2</sub>SO<sub>4</sub>)

**Membrana:** TFC-SR

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>0</sub>	1585,0294	1614,7685
A <sub>5</sub>	1556,6005	1615,5367
A <sub>24</sub>	1445,1863	1502,3183
P <sub>0</sub>	1273,8428	17,0872
P <sub>2</sub>	1517,2990	50,7100
P <sub>4</sub>	1177,4438	35,7737
P <sub>19</sub>	1316,8235	40,3262
P <sub>24</sub>	1296,2091	58,1424

#### **Experimento 02**

**Solução:** CaSO<sub>4</sub> 4000 mg/L (CaCl<sub>2</sub> + Na<sub>2</sub>SO<sub>4</sub>)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>0</sub>	1710,1741	1703,2073
P <sub>0</sub>	812,8047	
P <sub>21</sub>	771,1651	60,5286

#### **Experimento 03**

**Solução:** água do mar

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
P <sub>0</sub>	14990,3401	
P <sub>4</sub>	15454,8397	
P <sub>12</sub> ,	17487,0557	
P <sub>23</sub>	13595,9412	

### **Experimento 04**

**Solução:** NaCl 3000 mg/L

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>0</sub>	1412,3896	
P <sub>1</sub>	1570,5544	
P <sub>2</sub>	1571,1215	
P <sub>3</sub>	1520,3005	
P <sub>4</sub>	1722,7115	
P <sub>5</sub>	1667,2187	
P <sub>6</sub>	1271,1380	
P <sub>7</sub>	1253,9853	

### **Experimento 05**

**Solução:** água do mar

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>0</sub>	21608,1029	2415,8227
A <sub>f</sub>	21525,3915	3135,0385
P <sub>1</sub>	11347,9739	
P <sub>2</sub>	24487,1668	
P <sub>4</sub>	16331,3454	
P <sub>5</sub>	17180,5853	

### **Experimento 11**

**Solução:** CaSO<sub>4</sub> 4000 mg/L (CaCl<sub>2</sub> + Na<sub>2</sub>SO<sub>4</sub>)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>0</sub>	1824,1799	1777,5386
A <sub>f</sub>	1564,7300	1539,0488
P <sub>1</sub>	873,4385	
P <sub>2</sub>	853,0336	
P <sub>3</sub>	1559,0118	

### **Experimento 12**

**Solução:** água do mar

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>1</sub>	20427,1595	2236,1642
A <sub>2</sub>	19482,2807	2774,7330
A <sub>3</sub>	19832,8820	2832,9505
A <sub>5</sub>	19871,9841	2875,1280
A <sub>6</sub>	19681,6435	2866,7718
A <sub>7</sub>	27597,4562	3111,9182
P <sub>1</sub>	7254,7846	
P <sub>2</sub>	11950,3868	
P <sub>3</sub>	13062,5358	
P <sub>4</sub>	13598,0878	
P <sub>5</sub>	14199,7631	
P <sub>6</sub>	11743,8286	
P <sub>7</sub>	11924,5629	
P <sub>8</sub>	12565,5391	
P <sub>9</sub>	13386,0682	
P <sub>10</sub>	11474,0694	
P <sub>11</sub>	13030,9231	
P <sub>12</sub>	11875,6620	
P <sub>13</sub>	13323,4798	
P <sub>14</sub>	11950,7670	

### **Experimento 13**

**Solução:** Na<sub>2</sub>SO<sub>4</sub> 4000 mg/L

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>2</sub>		2631,9269
A <sub>3</sub>		2617,2789
A <sub>4</sub>		2559,3748
P <sub>2</sub>		6,7457
P <sub>3</sub>		6,5335
P <sub>4</sub>		6,4571

P <sub>5</sub>		6,7549
P <sub>6</sub>		5,5900
P <sub>7</sub>		5,5816
P <sub>8</sub>		5,2185
P <sub>10</sub>		4,8899
P <sub>11</sub>		5,4440
P <sub>12</sub>		5,2031

#### Experimento 14

**Solução:** K<sub>2</sub>SO<sub>4</sub> 4000 mg/L

**Membrana:** NF-90-400

amostra	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)
A <sub>1</sub>		2194,9828
A <sub>2</sub>		2058,1127
A <sub>3</sub>		2042,0873
A <sub>4</sub>		2078,3381
A <sub>5</sub>		2145,1834
A <sub>7</sub>		2173,1979
P <sub>1</sub>		34,6882
P <sub>2</sub>		24,1752
P <sub>3</sub>		26,8094
P <sub>4</sub>		13,2616
P <sub>5</sub>		17,4900
P <sub>6</sub>		16,0709
P <sub>7</sub>		8,8473
P <sub>8</sub>		10,3668
P <sub>9</sub>		9,1258
P <sub>10</sub>		8,1605
P <sub>11</sub>		8,1685
P <sub>12</sub>		8,7208
P <sub>13</sub>		8,1443
P <sub>14</sub>		8,1063
P <sub>15</sub>		8,5049

### **Experimento 15**

**Solução:** NaCl (3000 mg/L) + MgSO<sub>4</sub> (3000 mg/L)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>1</sub>	1613,9494	1154,7895
A <sub>2</sub>	1602,1106	1163,3529
A <sub>3</sub>	1540,0976	1122,2140
A <sub>4</sub>	1570,6629	1131,7798
A <sub>5</sub>	1585,1298	1155,4092
P <sub>1</sub>	894,5362	
P <sub>2</sub>	1137,3306	
P <sub>3</sub>	1199,4586	
P <sub>4</sub>	1182,1014	
P <sub>5</sub>	1135,4271	
P <sub>6</sub>	1247,0608	
P <sub>7</sub>	1122,2385	
P <sub>8</sub>	1111,6782	
P <sub>9</sub>	1121,8286	
P <sub>10</sub>	1212,0584	
P <sub>11</sub>	1078,0393	
P <sub>12</sub>	1081,4534	
P <sub>13</sub>	1085,0897	

### **Experimento 16**

**Solução:** NaCl(4000 mg/L) + K<sub>2</sub>SO<sub>4</sub> (4000 mg/L)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>1</sub>	2097,2674	2077,6081
A <sub>2</sub>	2033,3246	2058,3434
A <sub>3</sub>	2095,3243	2137,3144
A <sub>4</sub>	2093,7000	2120,5149
A <sub>5</sub>	2196,1997	2232,8556
A <sub>6</sub>	2072,3033	2137,1546
P <sub>1</sub>	1041,4110	
P <sub>2</sub>	1577,0171	

P <sub>3</sub>	1628,8474	
P <sub>4</sub>	1550,5194	
P <sub>5</sub>	1724,7470	
P <sub>6</sub>	1561,0582	
P <sub>7</sub>	1522,0283	
P <sub>8</sub>	1521,4467	
P <sub>9</sub>	1526,9935	
P <sub>10</sub>	1480,4528	
P <sub>11</sub>	1519,4856	
P <sub>12</sub>	1486,7147	
P <sub>13</sub>	1461,9997	
P <sub>14</sub>	1446,1521	

### Experimento 17

**Solução:** NaCl (24,53 g/L) + Na<sub>2</sub>SO<sub>4</sub> (4,09 g/L)

**Membrana:** NF-90-400

amostra	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)
A <sub>1</sub>	15501,0539	2708,0846
A <sub>2</sub>	15199,0699	2584,1996
A <sub>3</sub>	14452,0107	2625,3731
A <sub>4</sub>	14521,1369	2623,3379
A <sub>5</sub>	13199,3307	1872,2981
P <sub>1</sub>	13611,9670	
P <sub>2</sub>	12558,5029	
P <sub>3</sub>	12810,2085	
P <sub>4</sub>	13049,6352	
P <sub>5</sub>	13225,4728	
P <sub>6</sub>	13282,8716	
P <sub>7</sub>	13590,2208	
P <sub>8</sub>	13081,2756	
P <sub>9</sub>	13454,7210	
P <sub>10</sub>	13398,3237	

### **Experimento 18**

**Solução:** NaCl(24,53 g/L) + K<sub>2</sub>SO<sub>4</sub> (4g/L)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>1</sub>	12757,1897	1810,2412
A <sub>2</sub>	13214,8193	1862,2442
A <sub>3</sub>	14198,3203	1844,2242
A <sub>4</sub>	14079,2364	1804,0423
A <sub>6</sub>	12278,62	1631,4738
A <sub>7</sub>	12291,1913	1623,0489
A <sub>8</sub>	12419,5129	1637,4438
A <sub>9</sub>	12274,7811	1623,2658
P <sub>1</sub>	12129,0087	
P <sub>2</sub>	11739,4175	
P <sub>3</sub>	10832,5148	
P <sub>4</sub>	11977,5027	
P <sub>5</sub>	11762,9627	
P <sub>6</sub>	11928,36	
P <sub>7</sub>	12217,1036	
P <sub>8</sub>	10208,7765	
P <sub>9</sub>	10559,7079	
P <sub>10</sub>	10995,2679	

### **Experimento 19**

**Solução:** NaCl(24,53 g/L) + MgSO<sub>4</sub> (4000 mg/L)

**Membrana:** NF-90-400

<b>amostra</b>	<b>Cl<sup>-</sup> (mg/L)</b>	<b>SO<sub>4</sub> (mg/L)</b>
A <sub>1</sub>	13119,9052	1068,2839
A <sub>2</sub>	11202,5886	892,2541
A <sub>3</sub>	10402,9425	944,3869
A <sub>4</sub>	9811,9126	790,6951
A <sub>5</sub>	9423,7680	760,6918
A <sub>6</sub>	10726,6790	972,5991
P <sub>1</sub>	9492,4438	
P <sub>2</sub>	10073,2646	

P <sub>3</sub>	9805,8287	
P <sub>4</sub>	9331,2103	
P <sub>5</sub>	10560,8562	
P <sub>6</sub>	10454,9698	
P <sub>7</sub>	10599,3895	
P <sub>8</sub>	8566,0308	
P <sub>9</sub>	10141,2354	
P <sub>10</sub>	9388,8538	

**Experimento 20****Solução:** NaCl(24,53 g/L) + MgSO<sub>4</sub> (4000 mg/L)**Membrana:** NF-90-400

amostra	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)
A <sub>1</sub>	10425,6019	256,6226
A <sub>2</sub>	10006,1227	261,8356
A <sub>3</sub>	8809,2806	237,7923
A <sub>4</sub>	9340,1153	247,0098
A <sub>5</sub>	8206,3849	226,3781
A <sub>6</sub>	9113,7003	250,0197
P <sub>1</sub>	5373,3239	
P <sub>2</sub>	6669,9259	
P <sub>3</sub>	7309,3846	
P <sub>4</sub>	6754,8316	
P <sub>5</sub>	8829,1157	
P <sub>6</sub>	6575,1989	
P <sub>7</sub>	7012,8130	
P <sub>8</sub>	6418,6816	
P <sub>9</sub>	6801,3790	
P <sub>10</sub>	7849,8914	

**Experimento 21****Solução:** água do mar**Membrana:** NF-90-400

amostra	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)
A <sub>1</sub>	13952,6877	1475,5996

A <sub>2</sub>	17096,4901	1930,3183
A <sub>3</sub>	17723,2852	1987,8795
A <sub>4</sub>	17315,8772	1929,4888
A <sub>5</sub>	17155,3215	1899,5797
A <sub>6</sub>	16868,1663	1867,7437
P <sub>1</sub>	7723,5850	
P <sub>2</sub>	12416,1656	
P <sub>3</sub>	12724,7368	
P <sub>4</sub>	12065,9891	
P <sub>5</sub>	12840,5543	
P <sub>6</sub>	12391,9921	
P <sub>7</sub>	13345,2205	
P <sub>8</sub>	9979,3239	

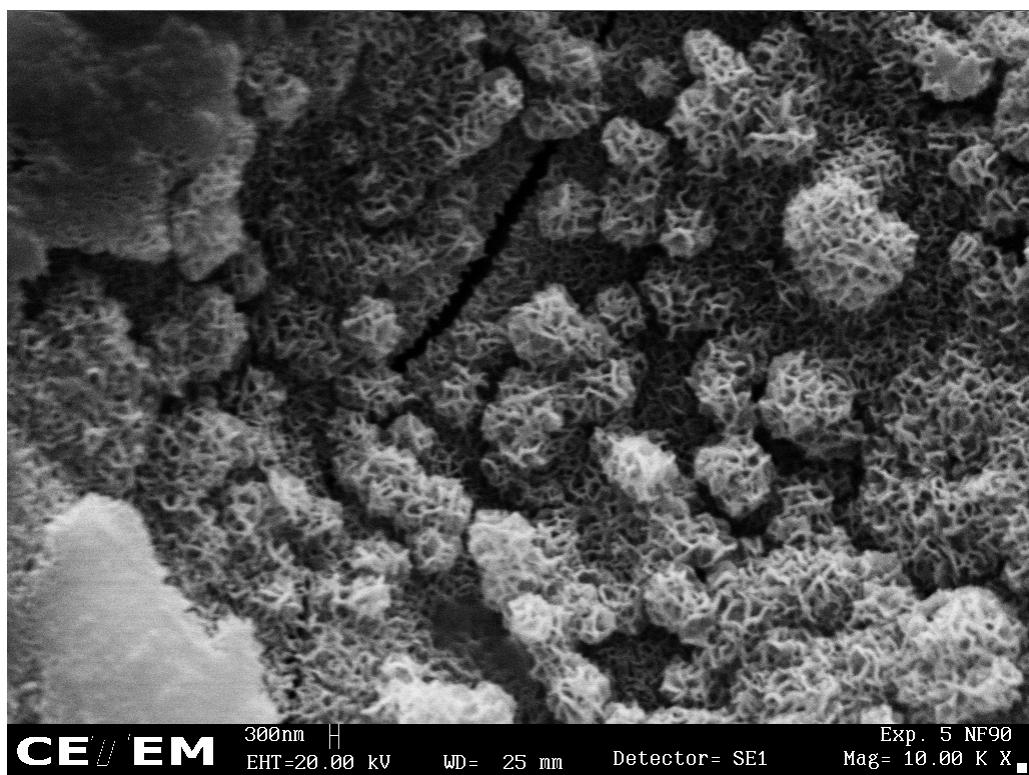
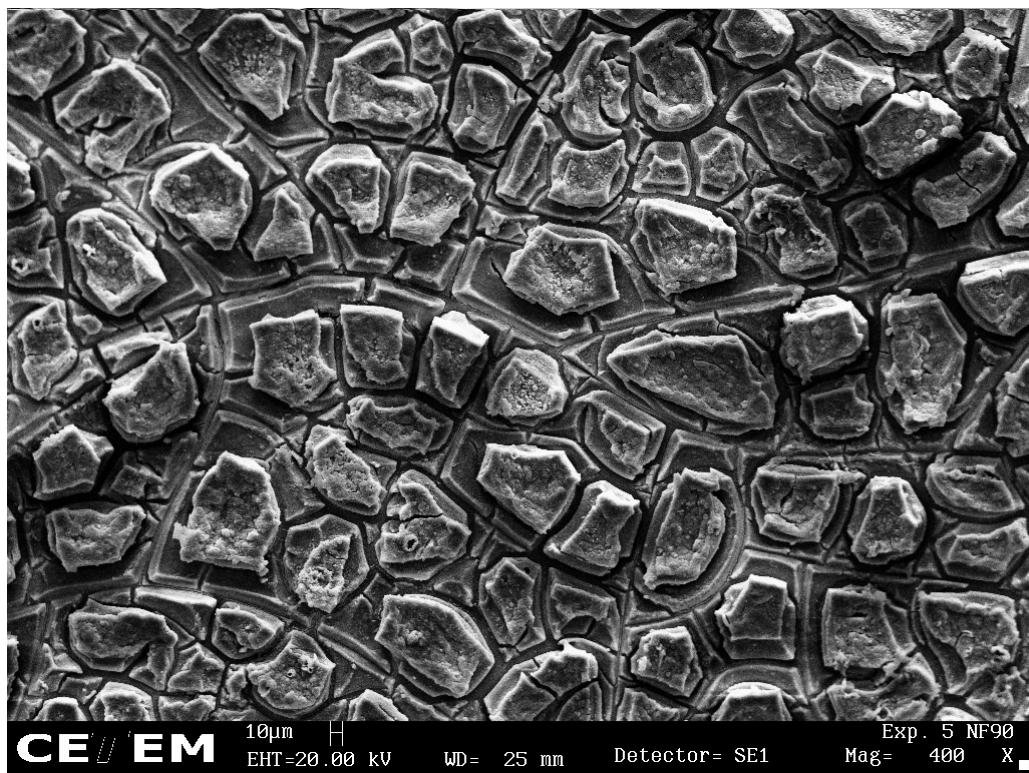
### Experimento 22

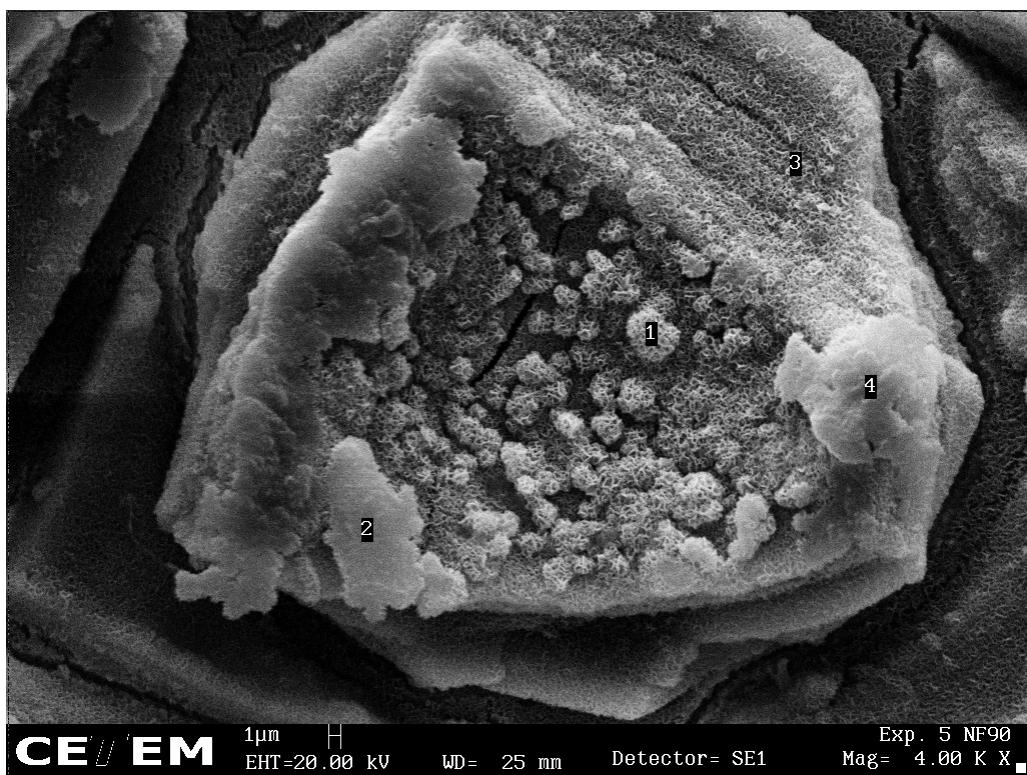
**Solução:** água do mar

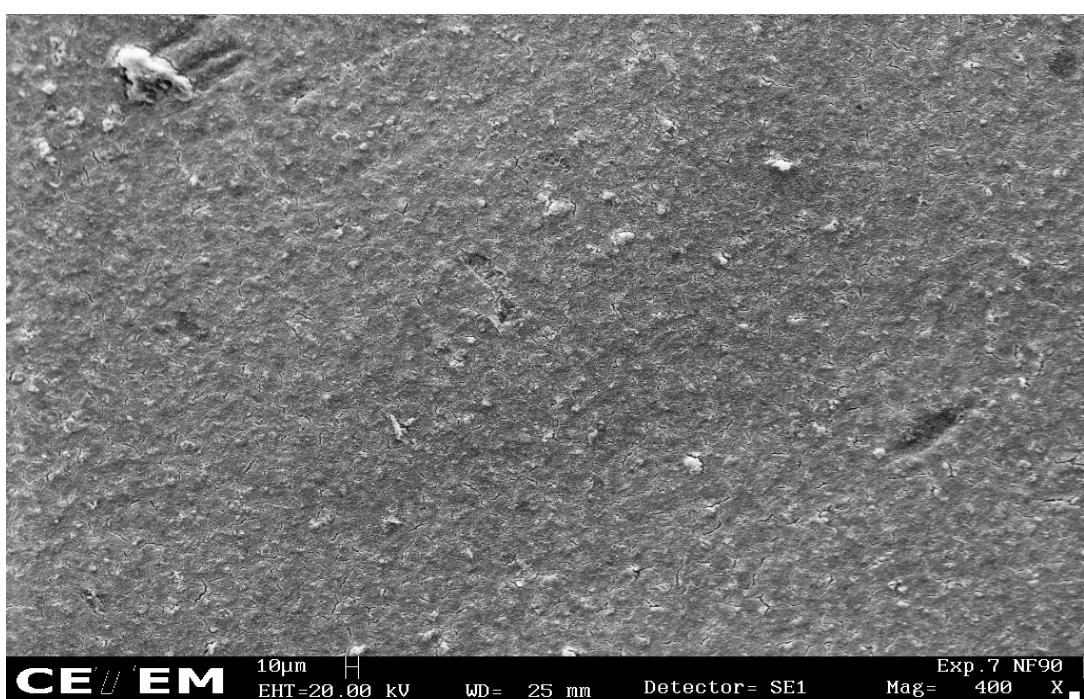
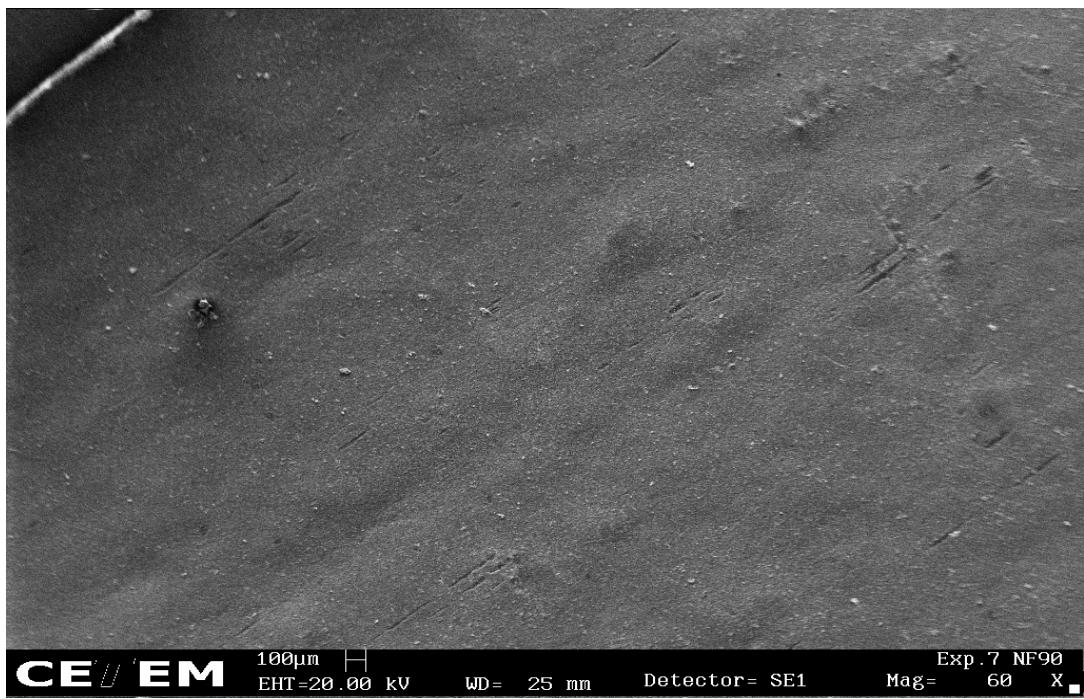
**Membrana:** NF-90-400

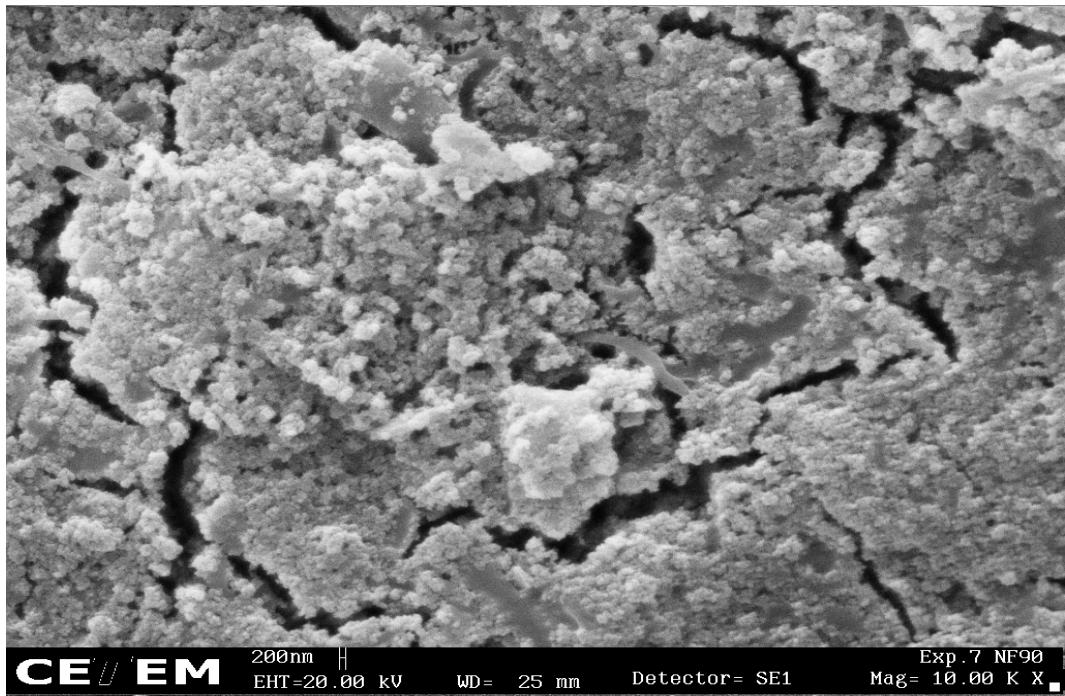
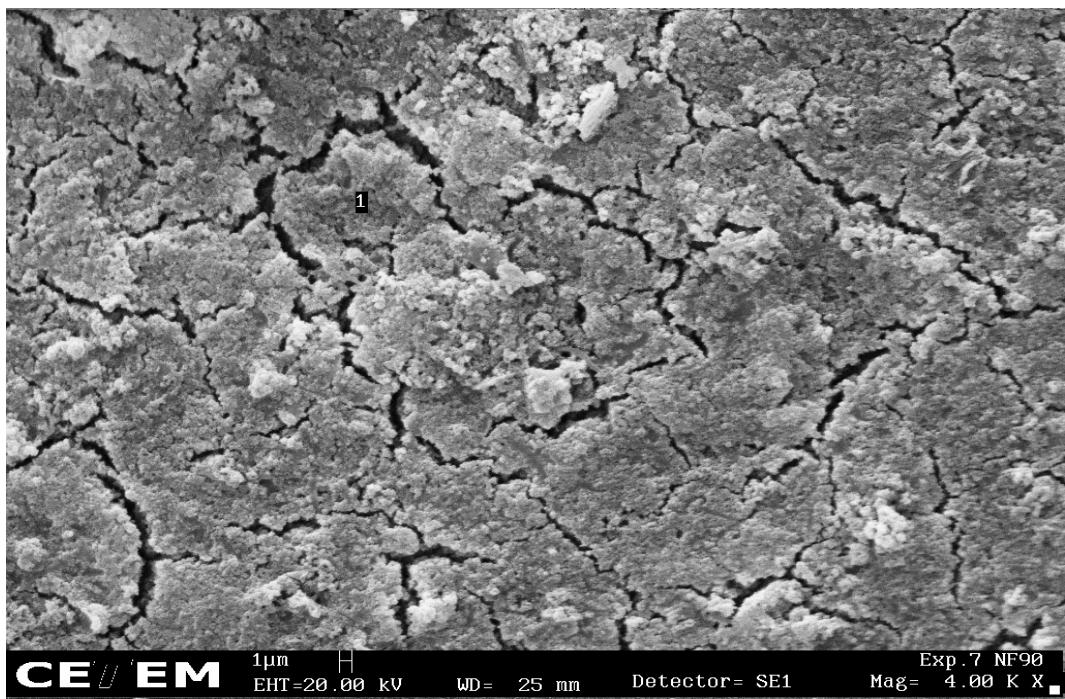
amostra	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)
A <sub>1</sub>	15239,6771	1677,3542
A <sub>2</sub>	14715,9880	1621,9338
A <sub>3</sub>	14509,1136	1598,7042
A <sub>4</sub>	14110,7846	1535,0203
A <sub>5</sub>	13790,0847	1488,1785
A <sub>6</sub>	11684,5594	1275,1670
P <sub>1</sub>	10351,1579	
P <sub>2</sub>	9038,6926	
P <sub>3</sub>	10031,1620	
P <sub>4</sub>	9398,4465	
P <sub>5</sub>	9644,0618	
P <sub>6</sub>	10084,2093	

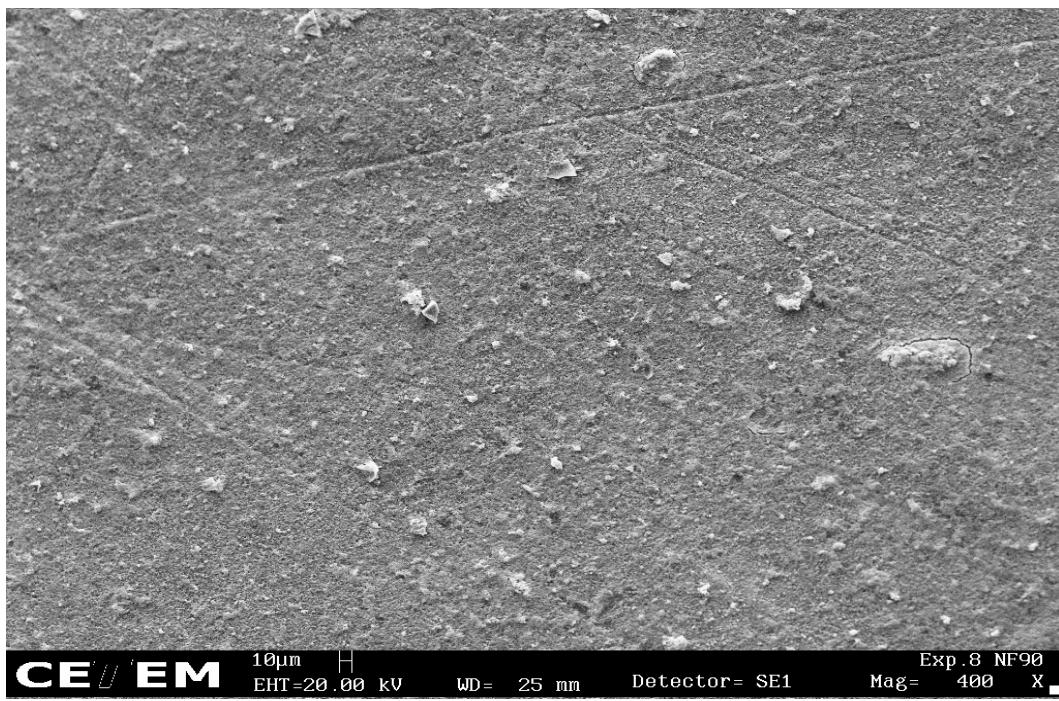
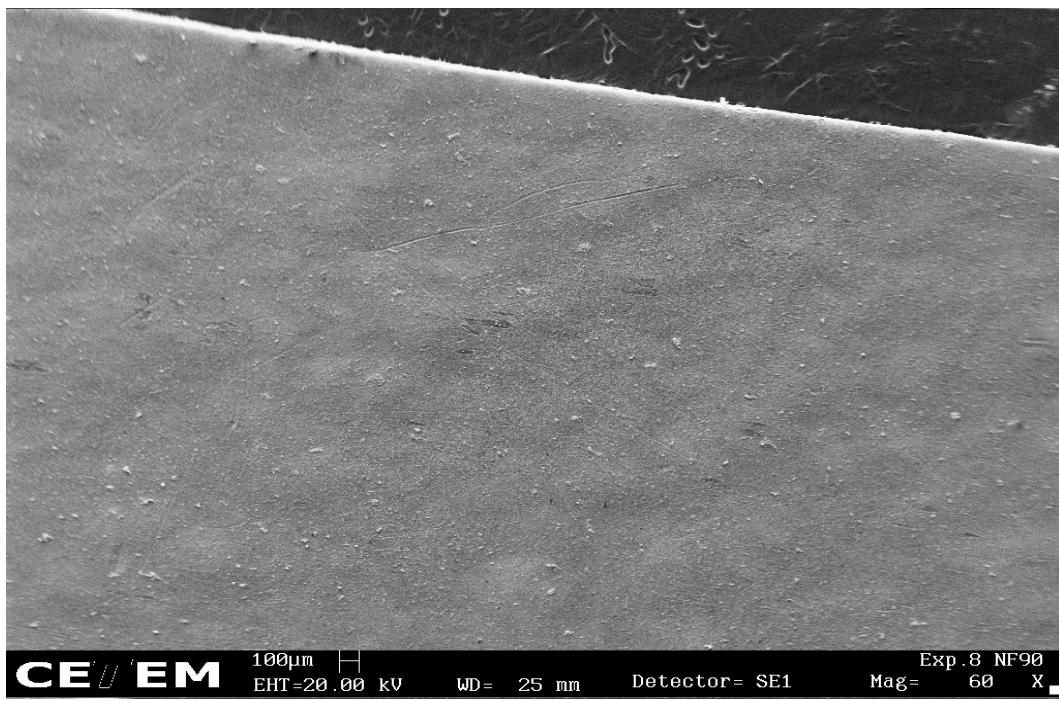
# **ANEXO IV**

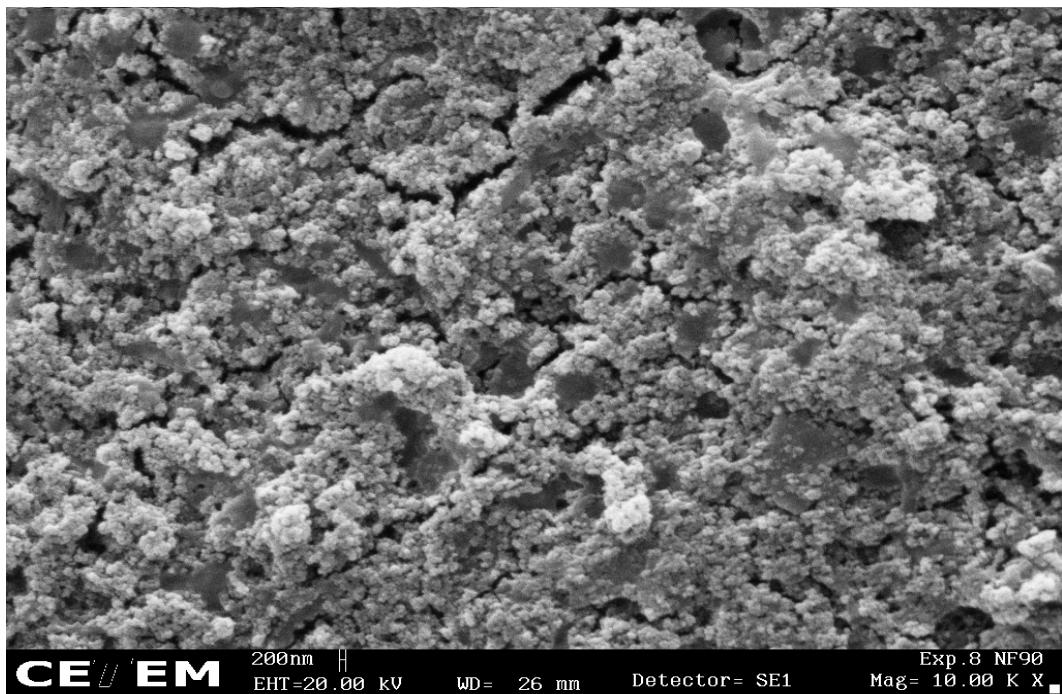
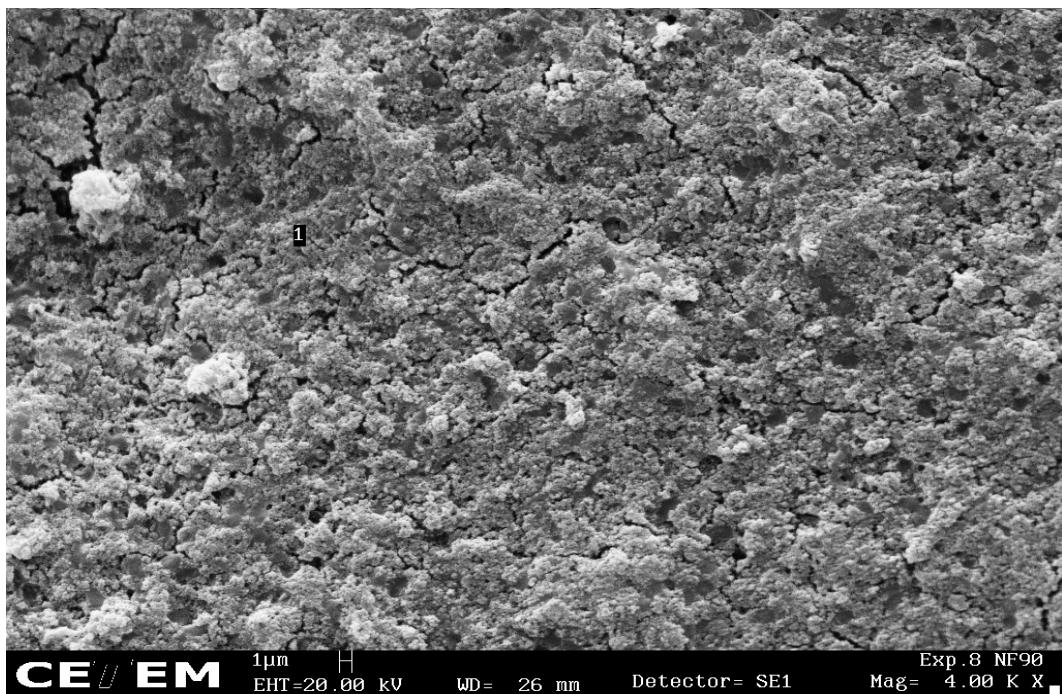
**ANEXO IV**

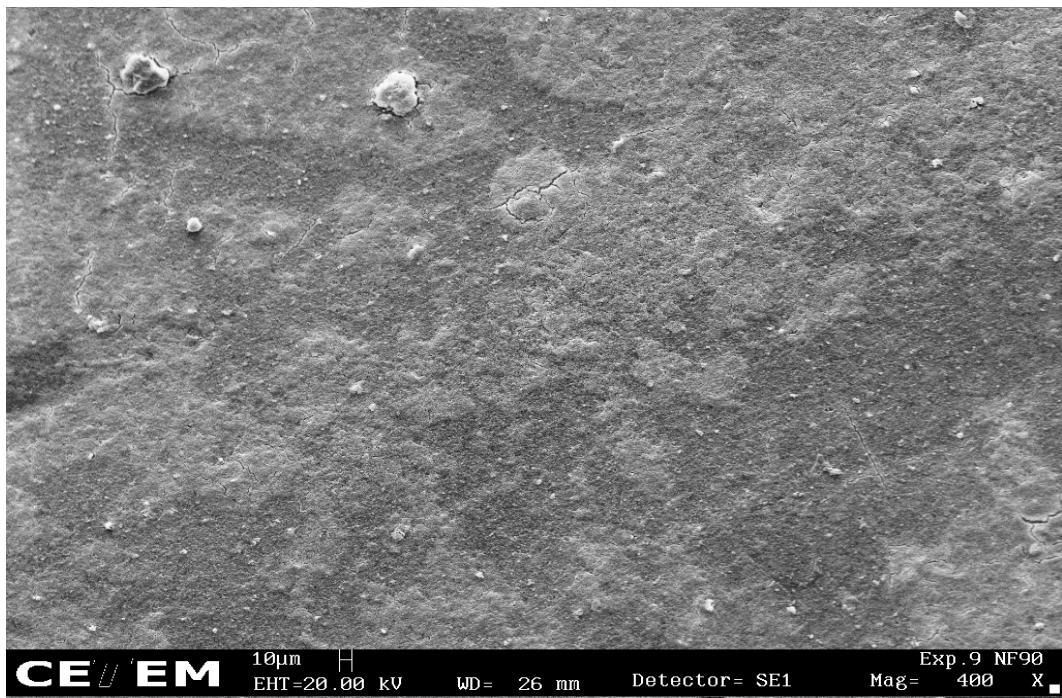
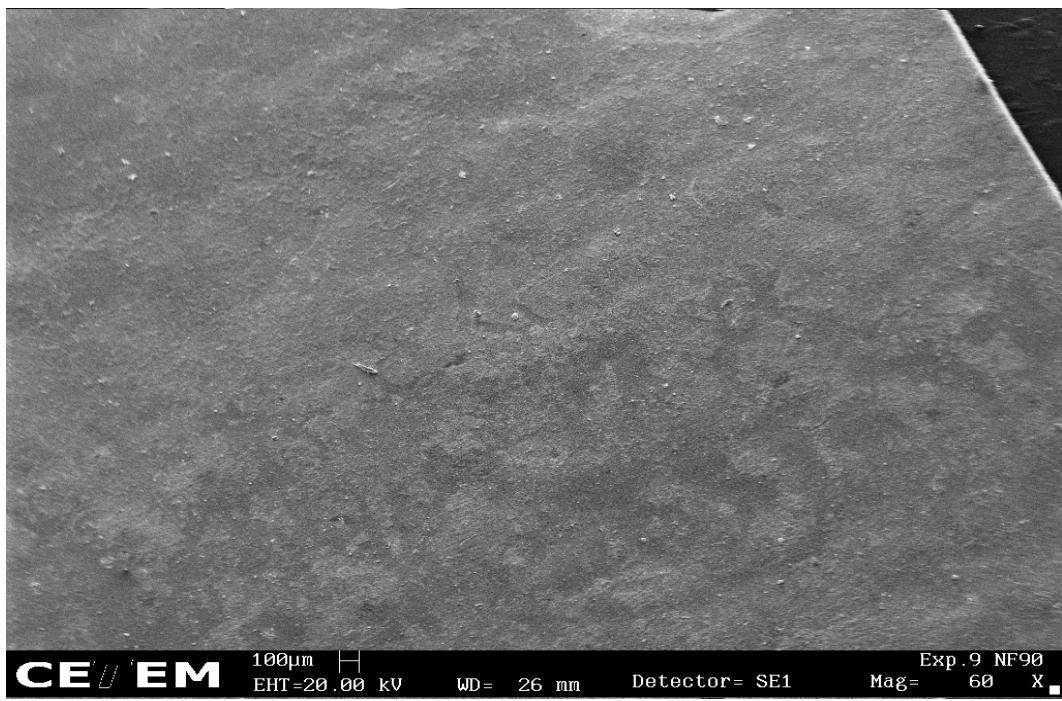


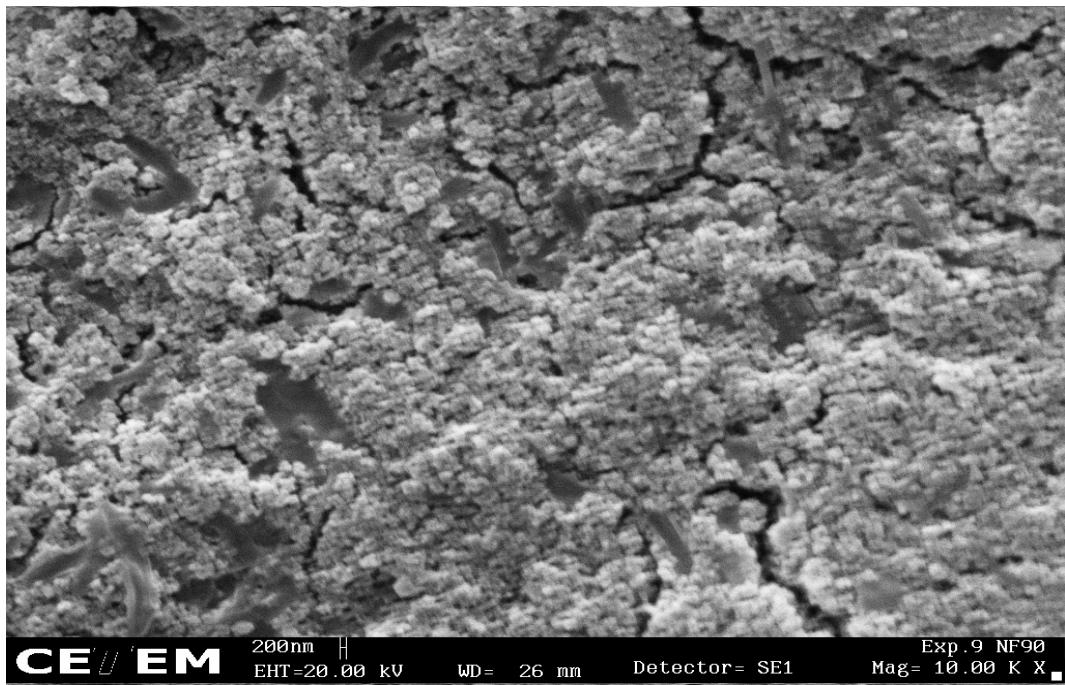
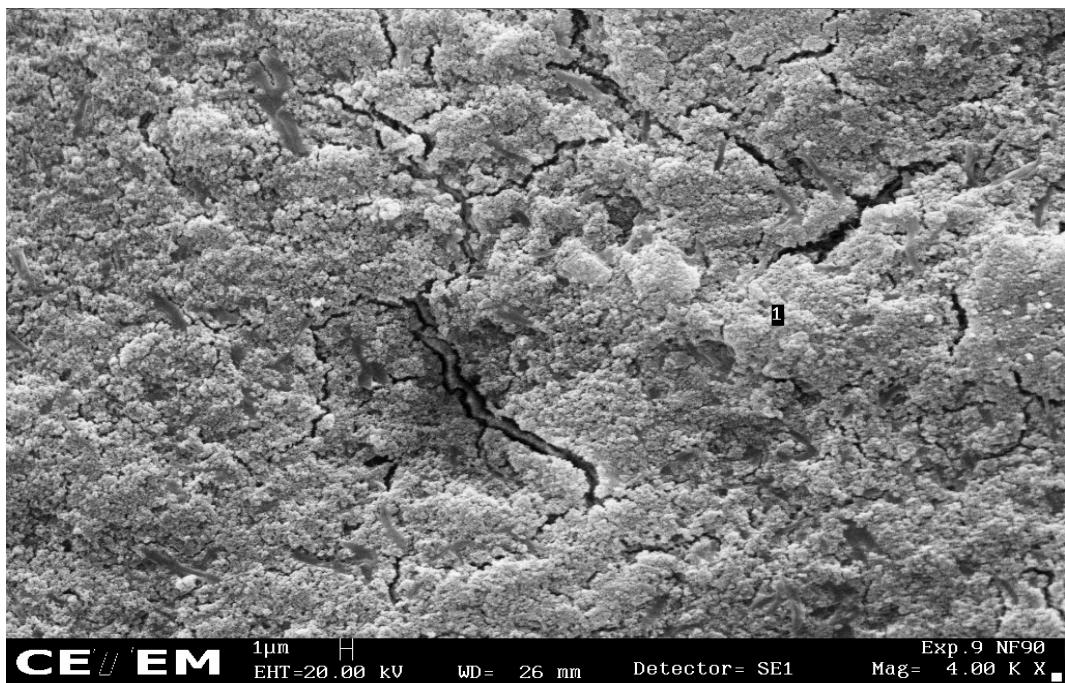


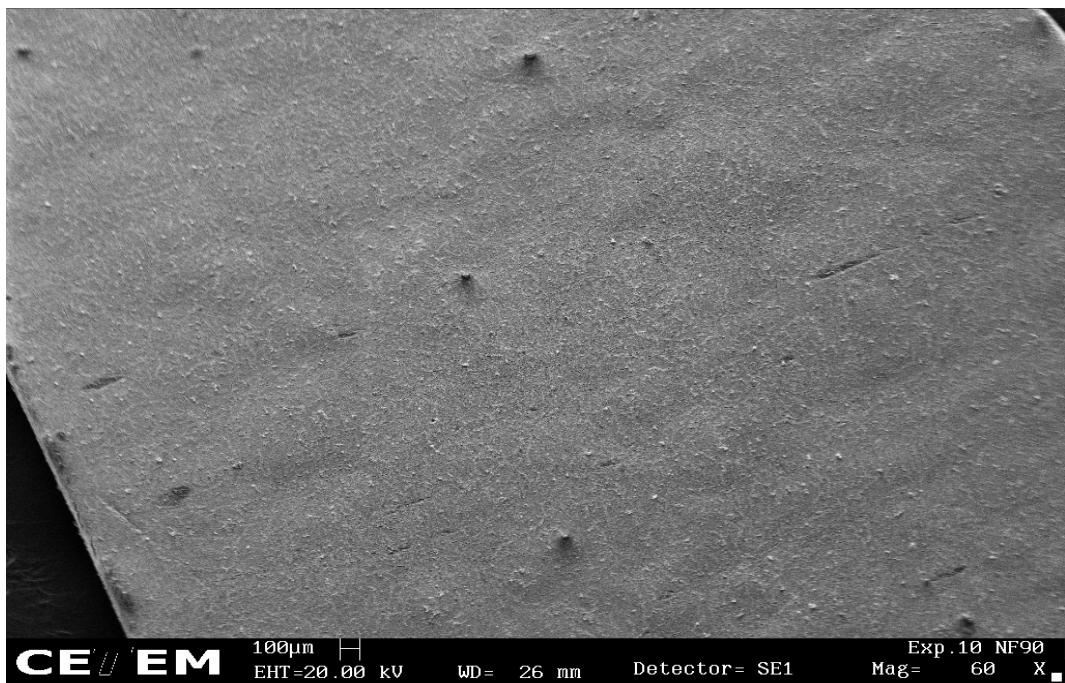




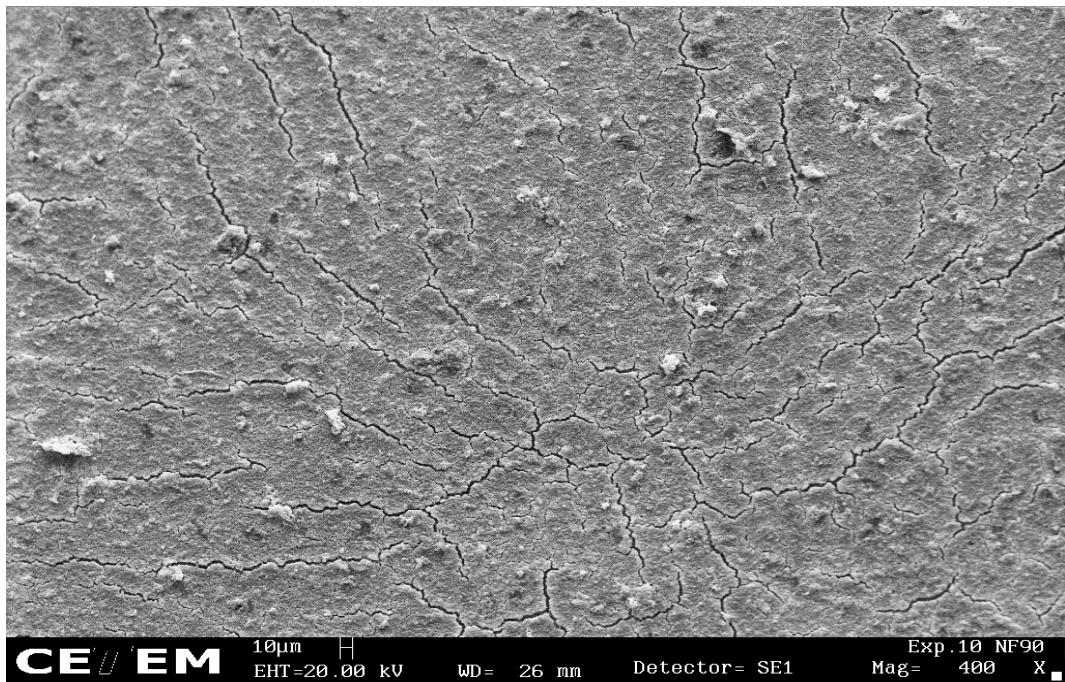


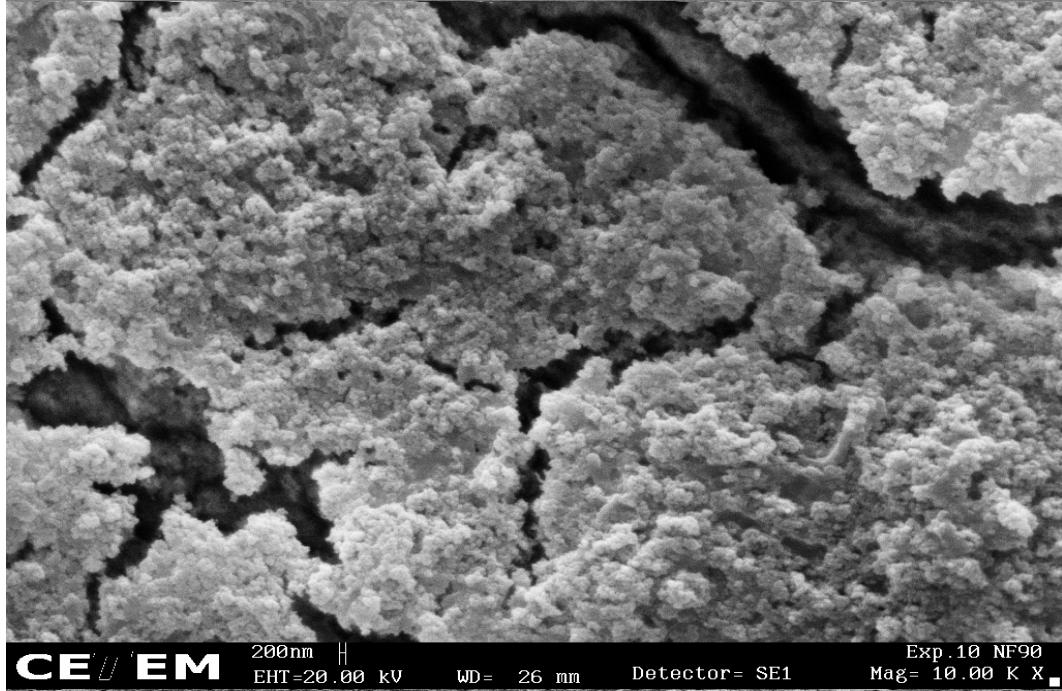
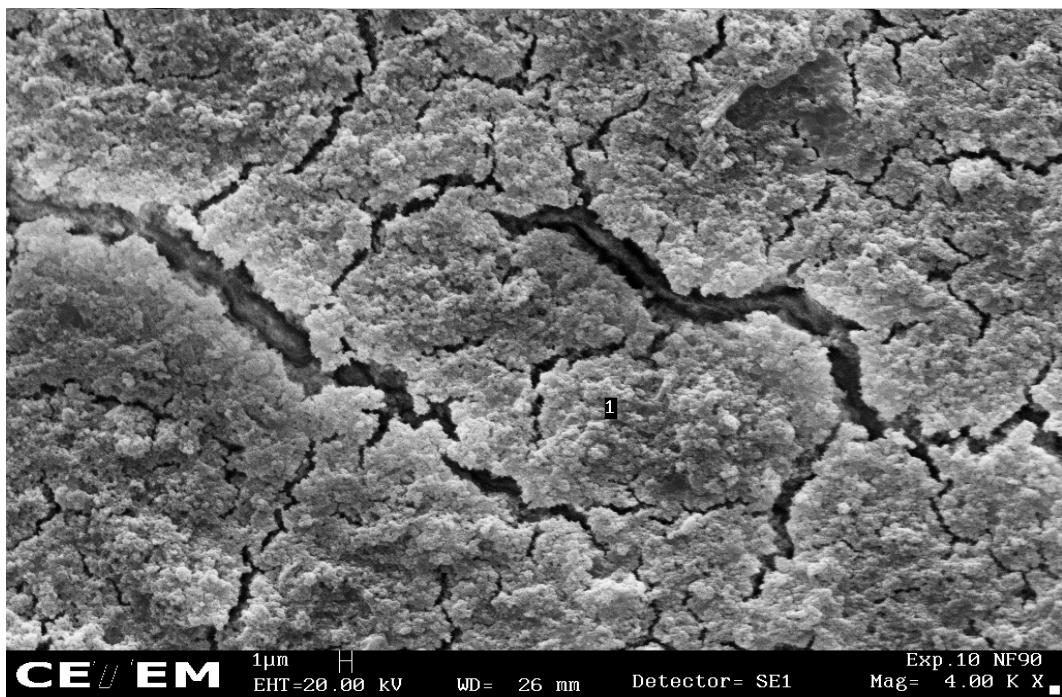


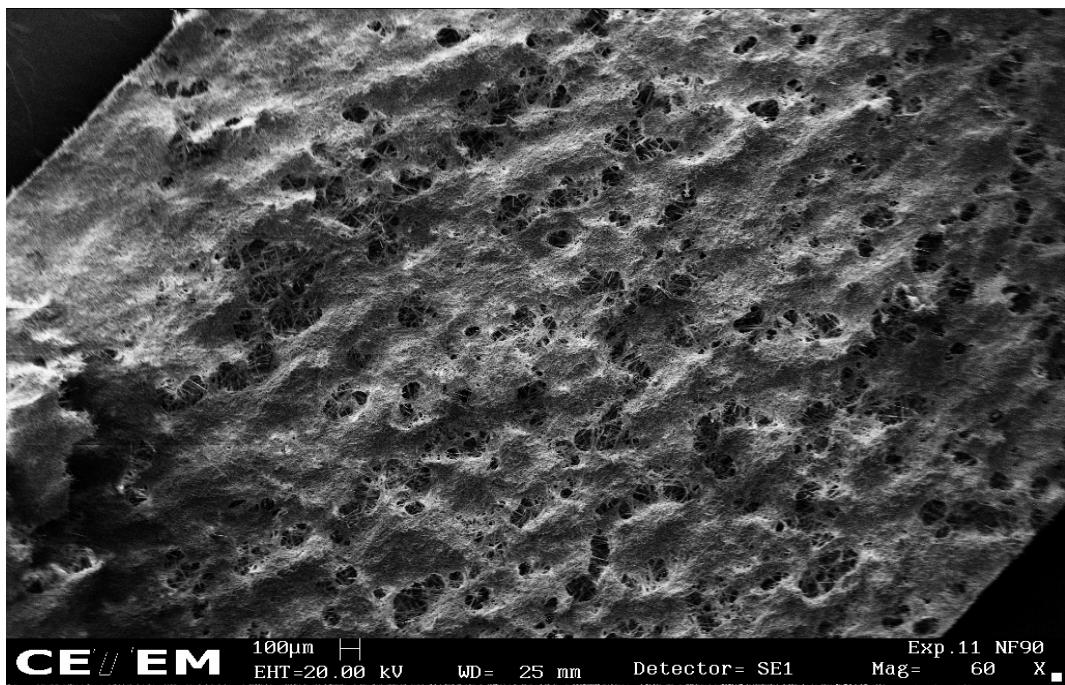




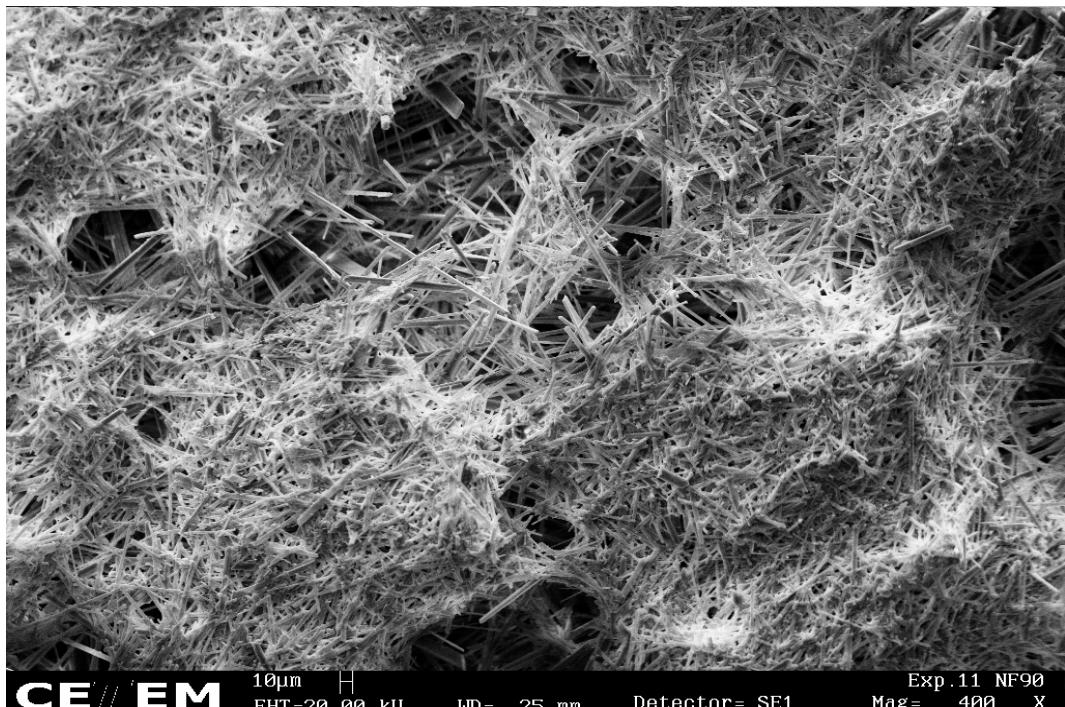
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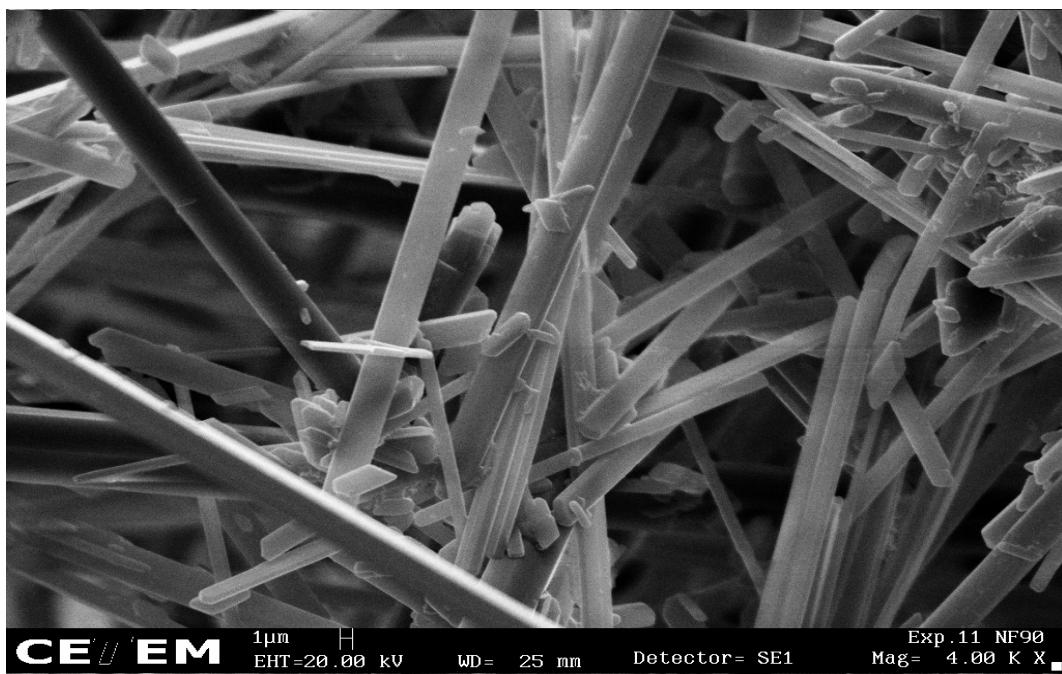
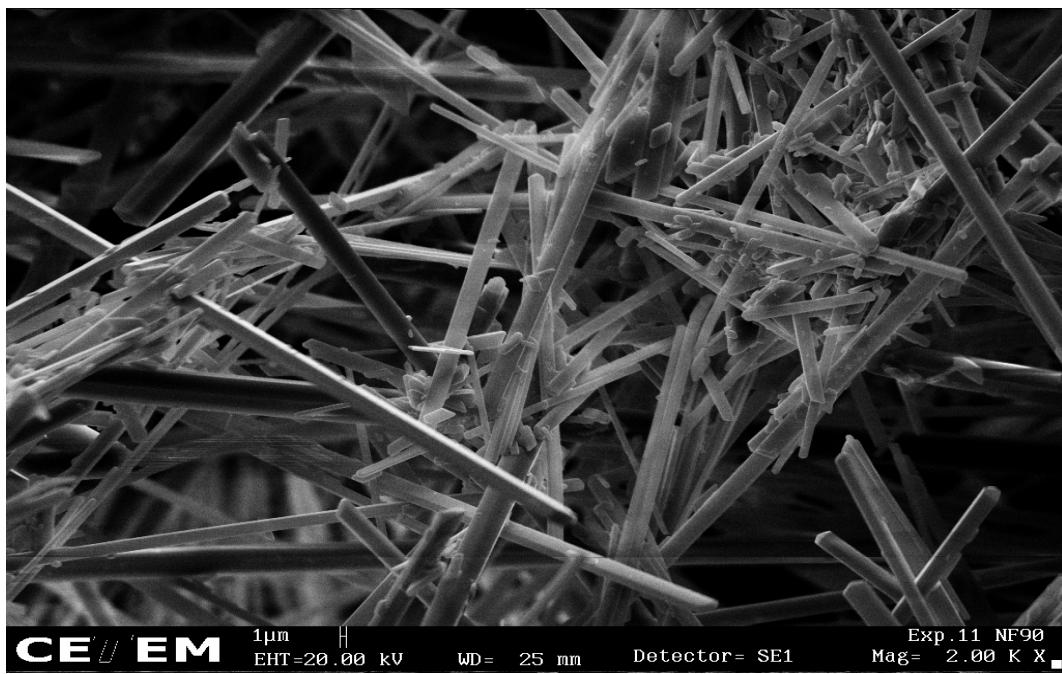


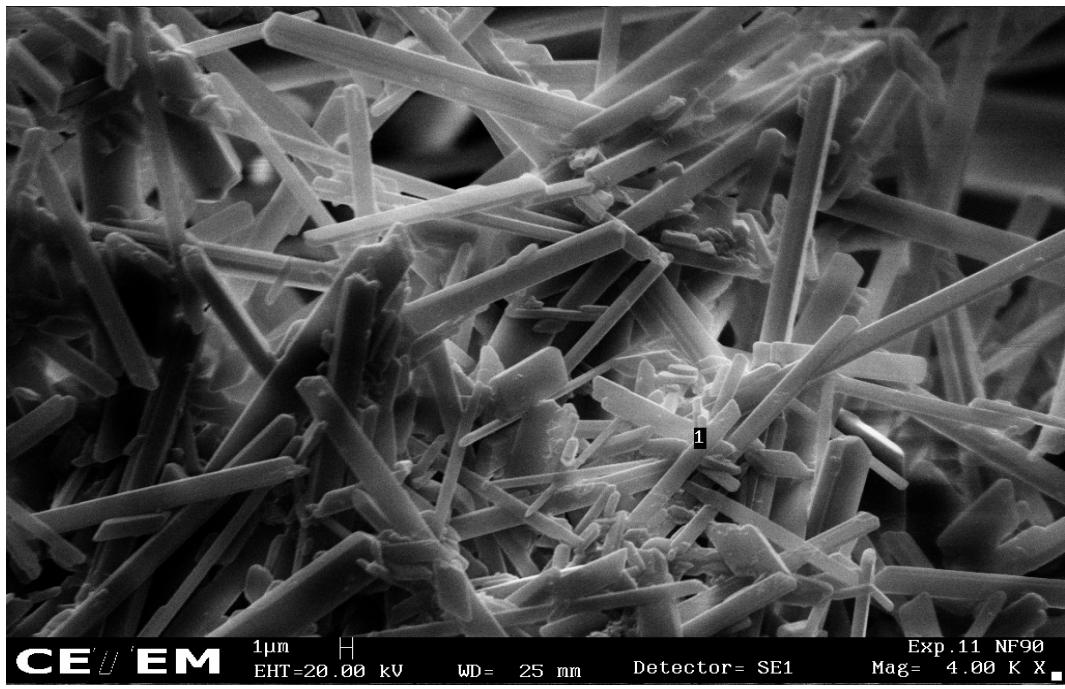


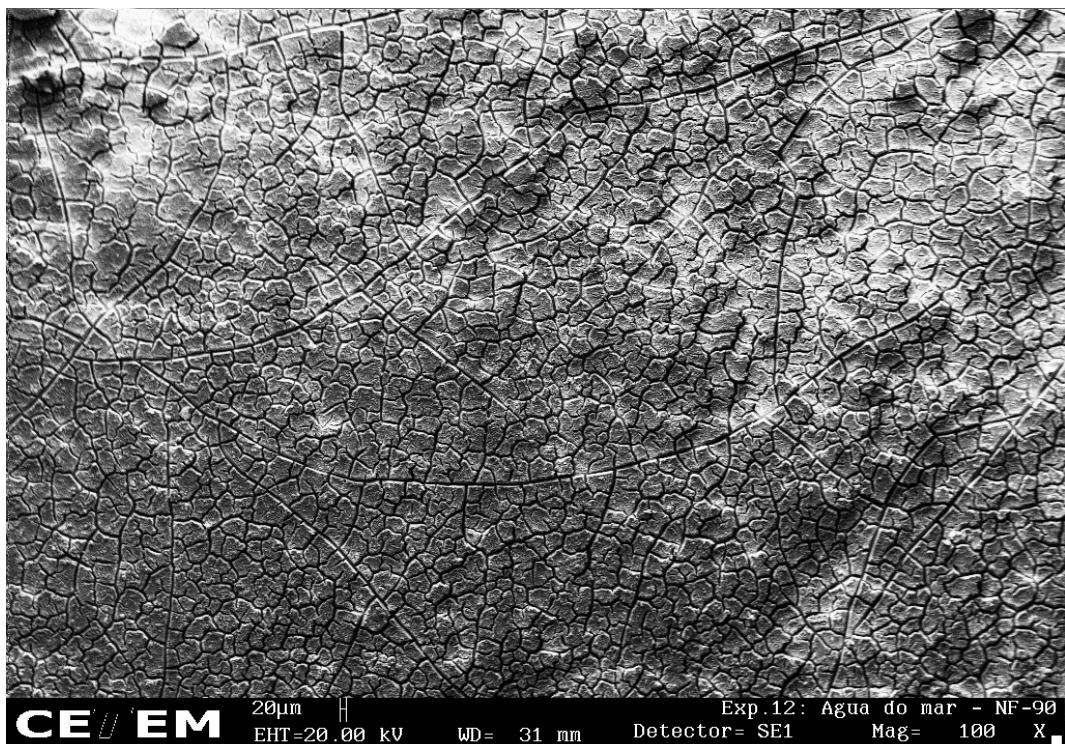
**CE / EM** 100µm EHT=20.00 kV WD= 25 mm Detector= SE1 Exp.11 NF90 Mag= 60 X ■



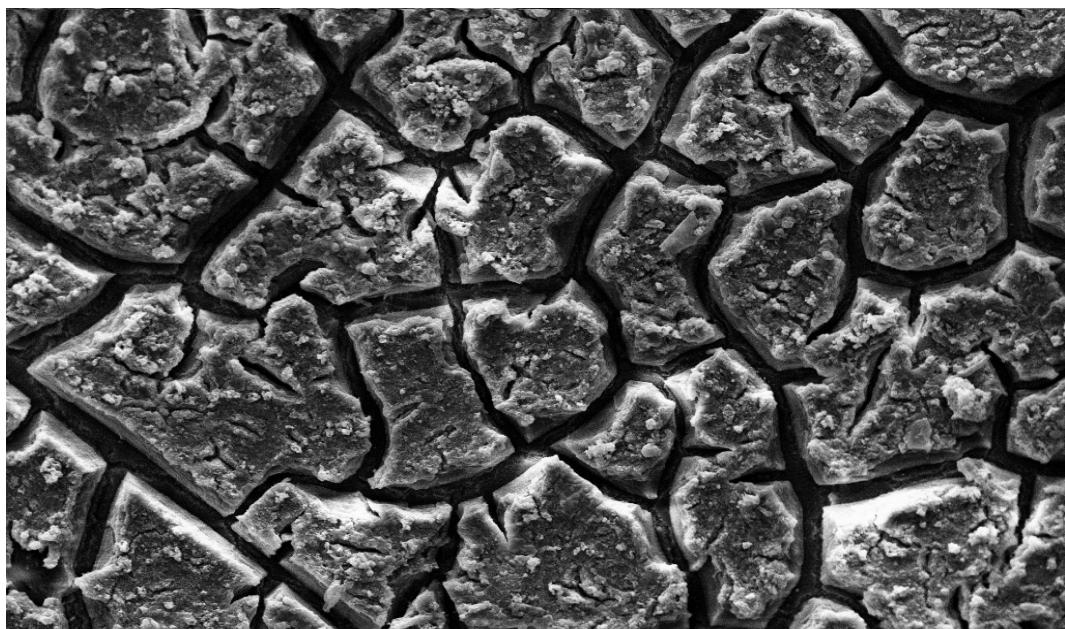
**CE / EM** 10µm EHT=20.00 kV WD= 25 mm Detector= SE1 Exp.11 NF90 Mag= 400 X ■







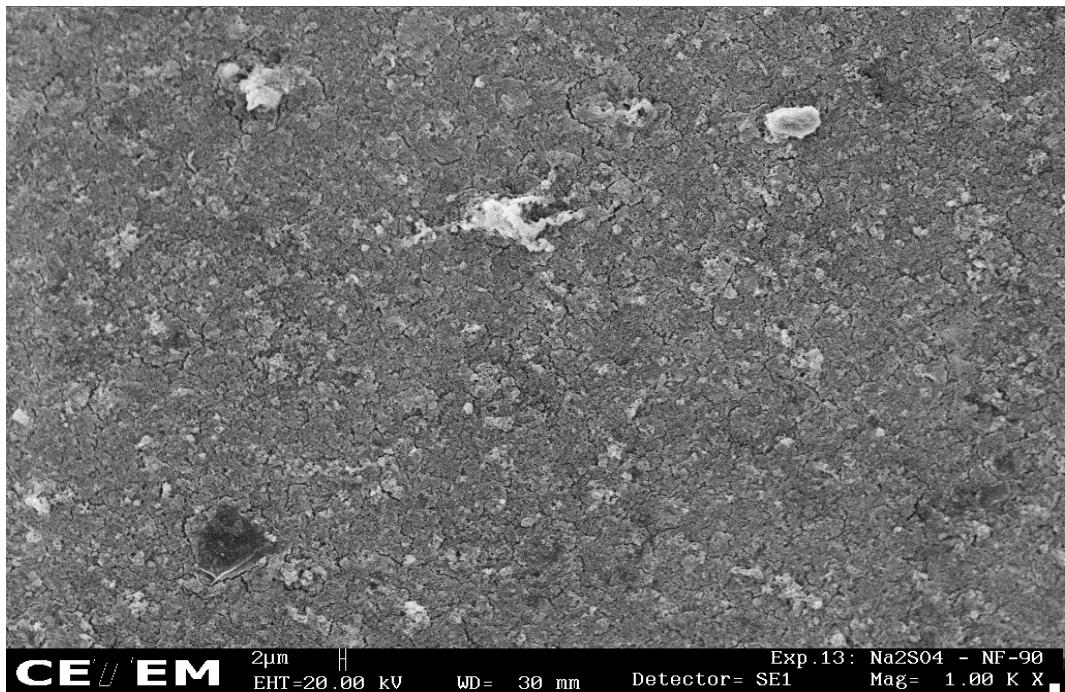
**CE / EM** 20µm H  
EHT=20.00 kV WD= 31 mm Detector= SE1 Mag= 100 X ■  
Exp.12: Água do mar - NF-90

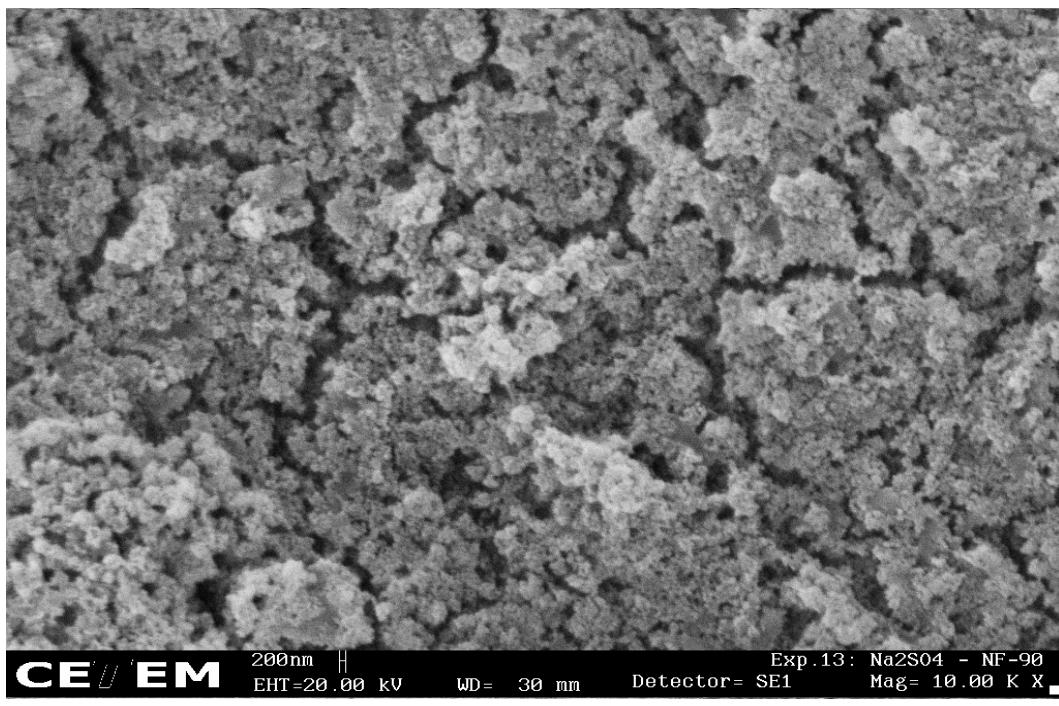


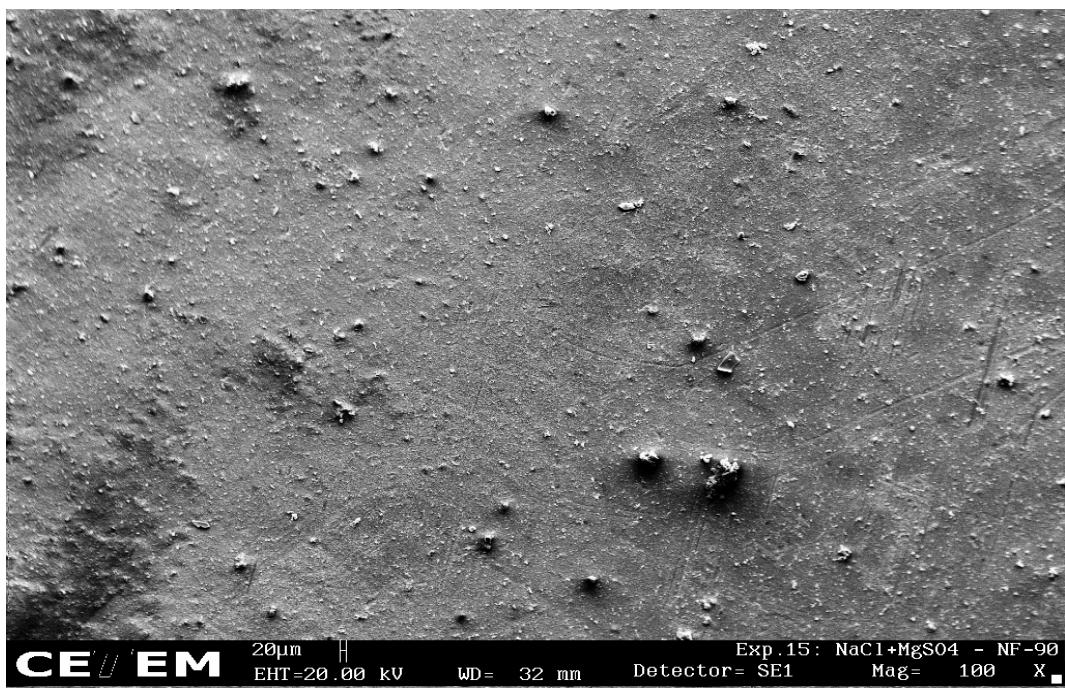
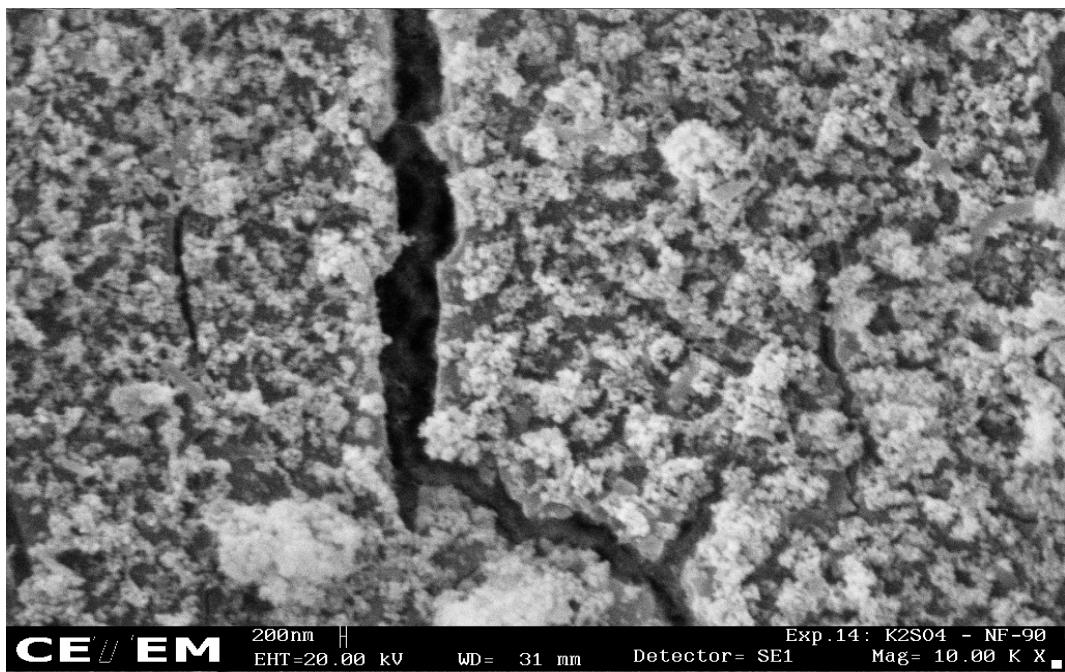
**CE / EM** 2µm H  
EHT=20.00 kV WD= 31 mm Detector= SE1 Mag= 1.00 K X ■  
Exp.12: Água do mar - NF-90

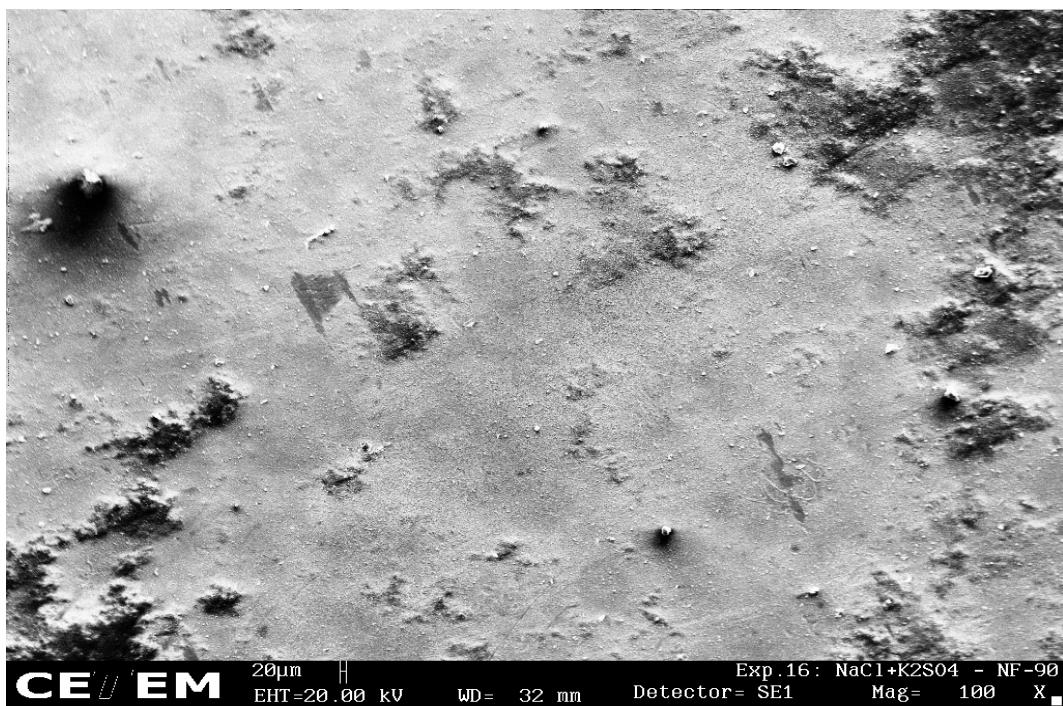
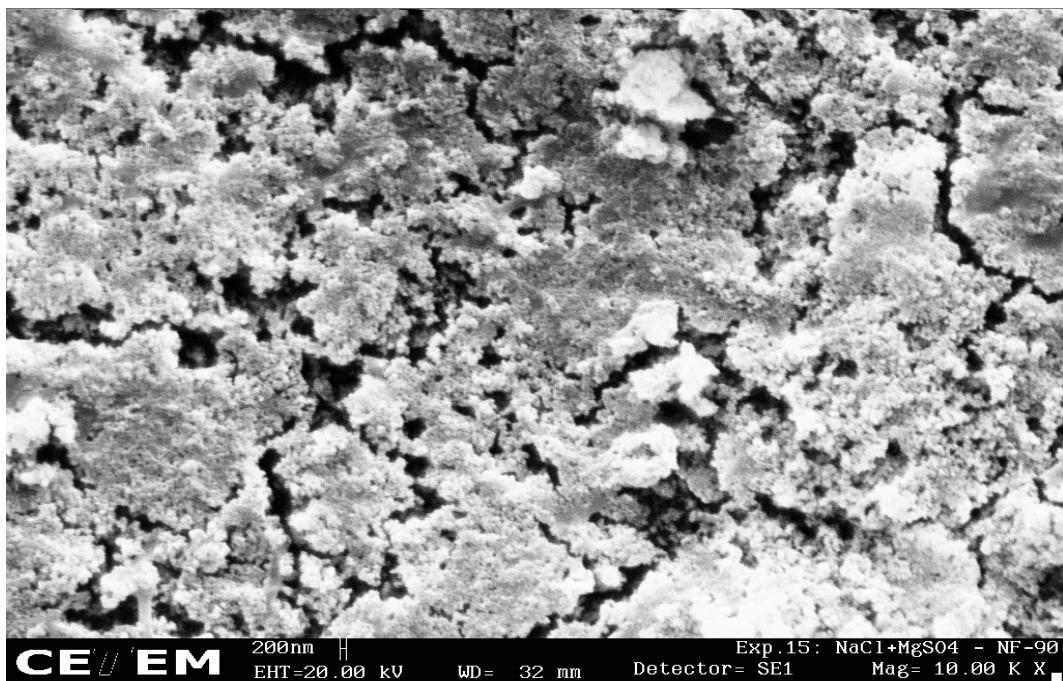


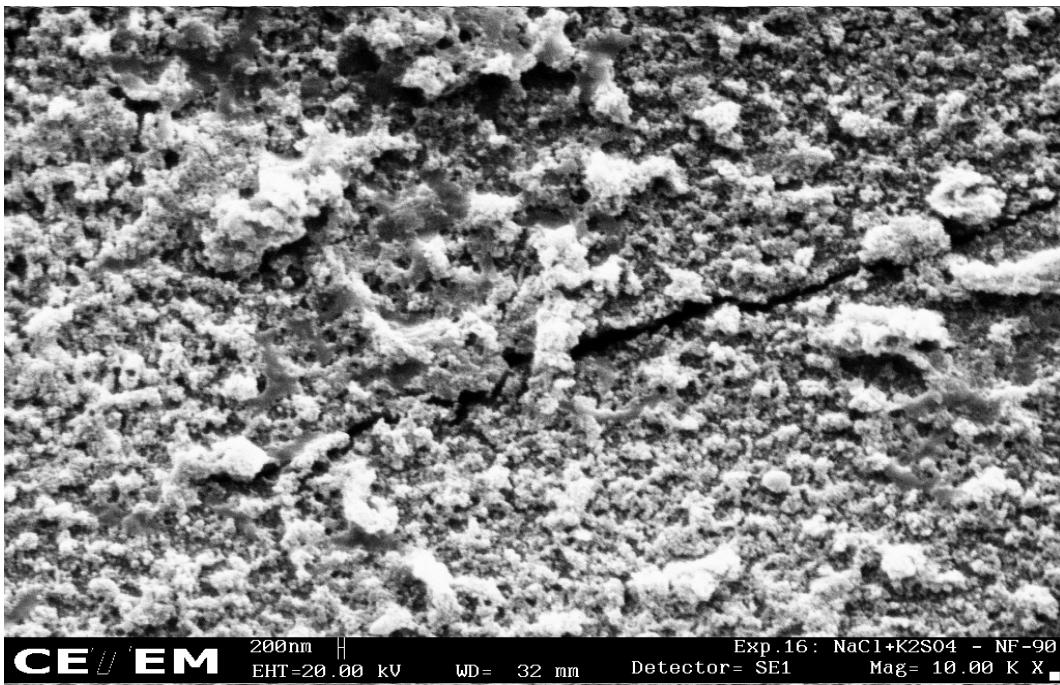
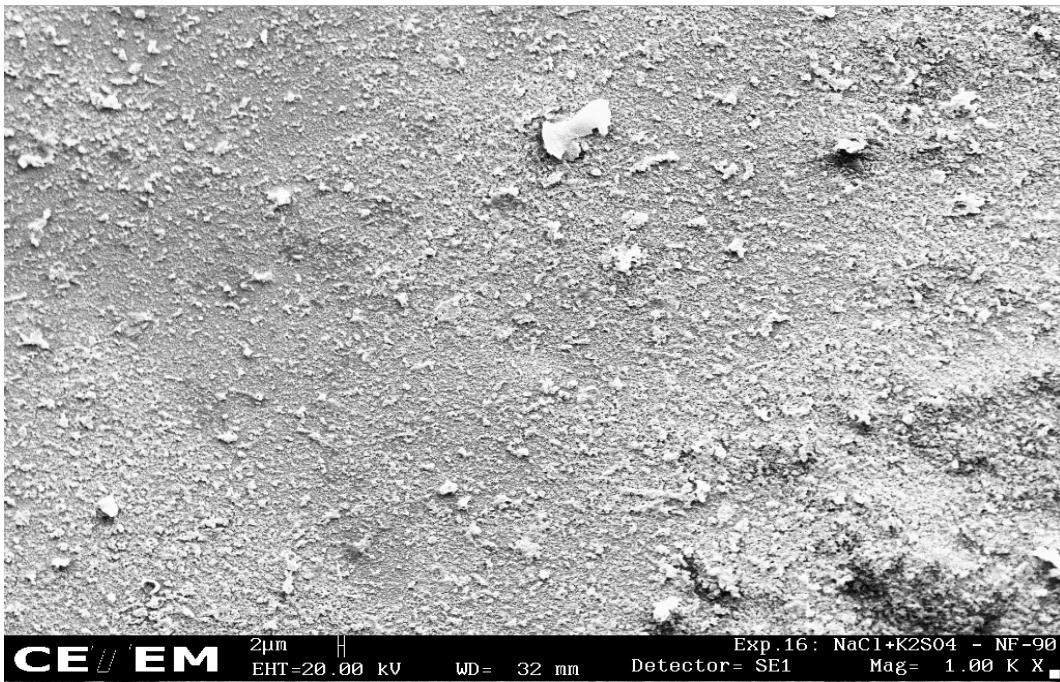
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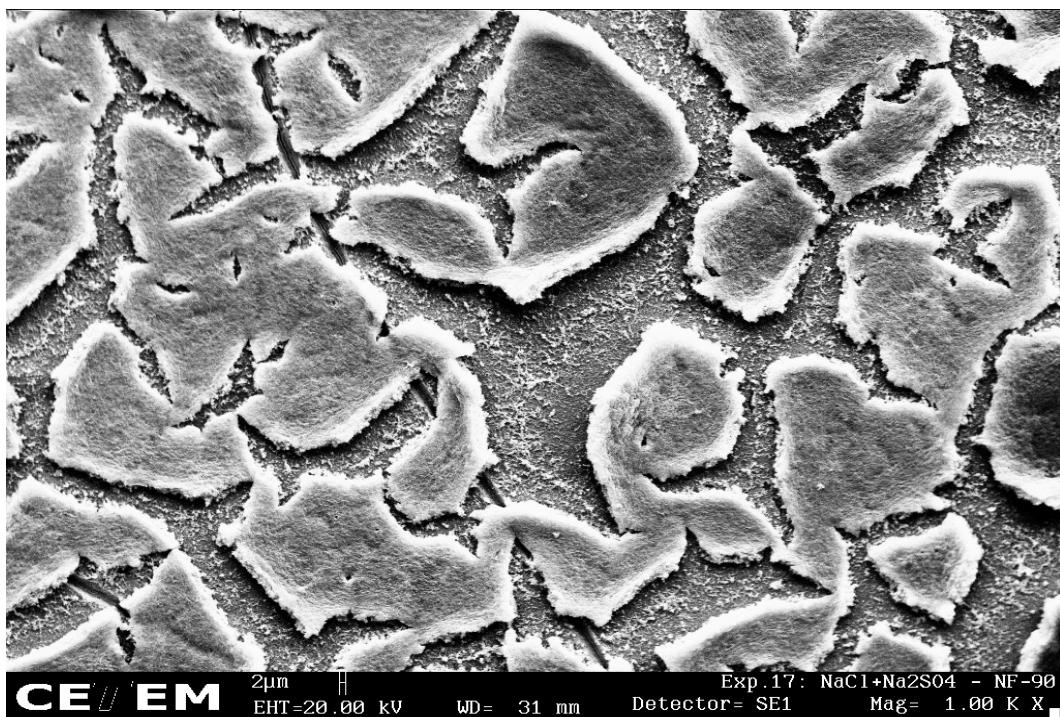


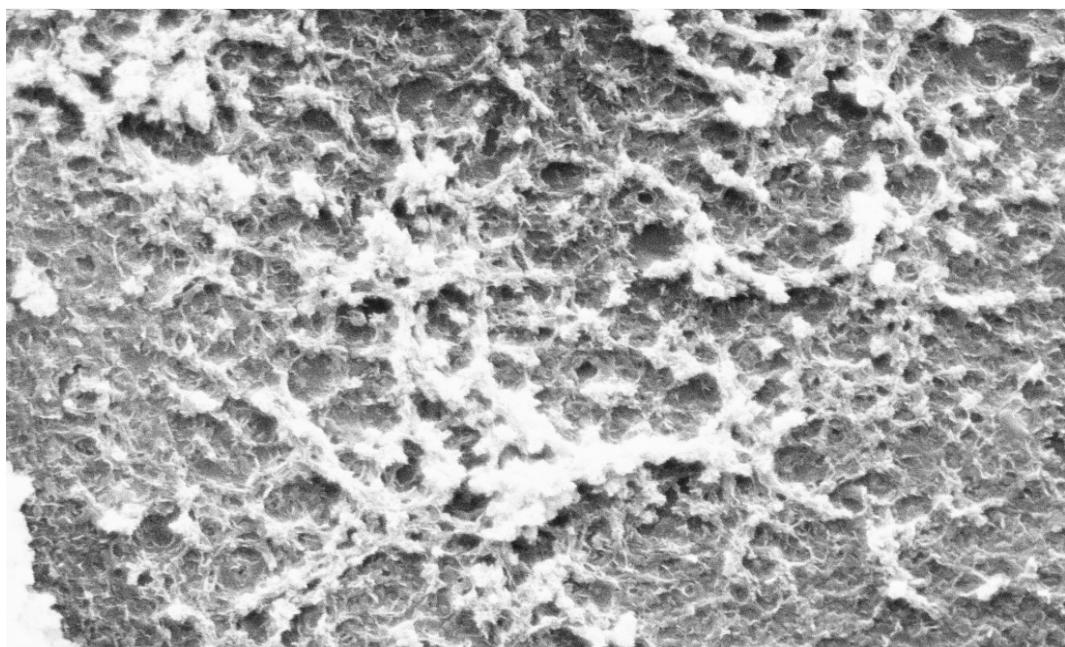




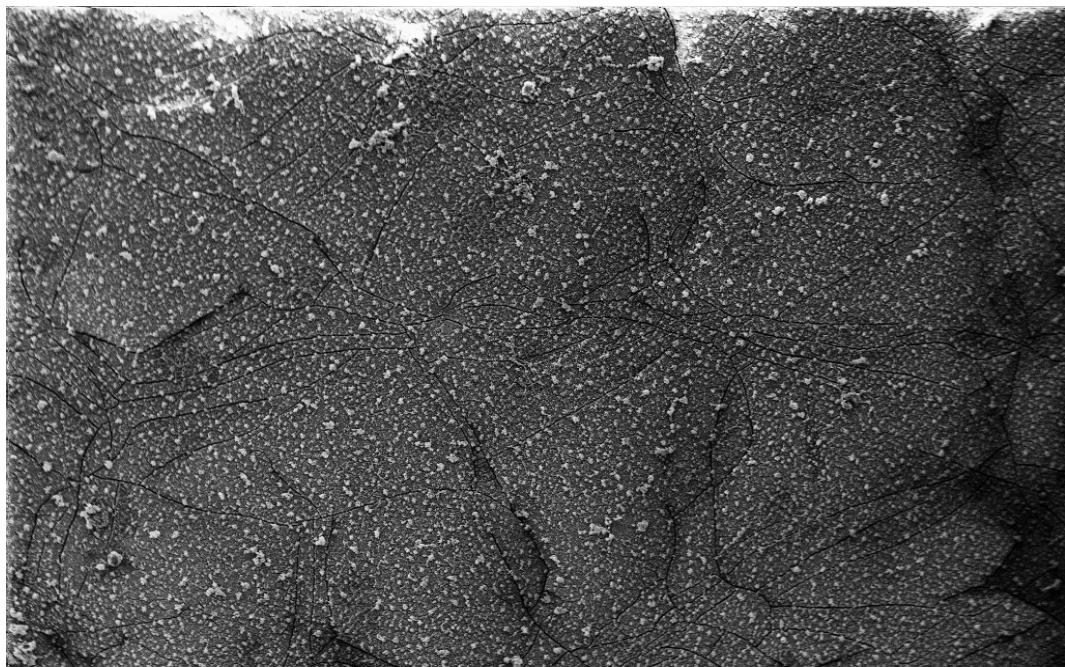




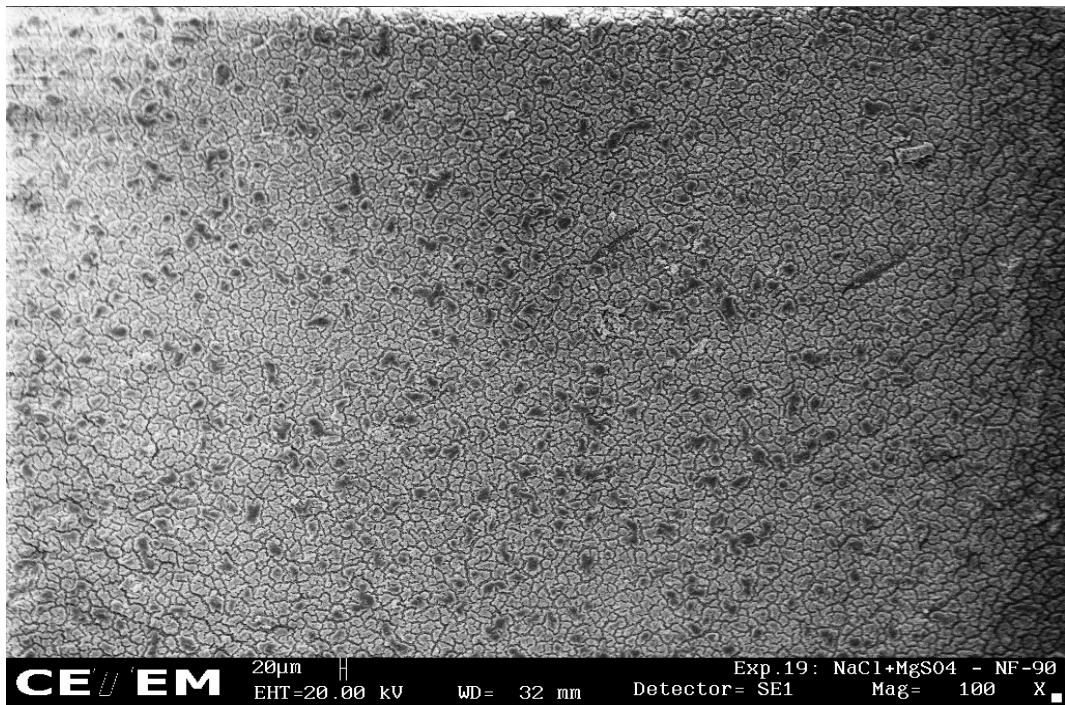
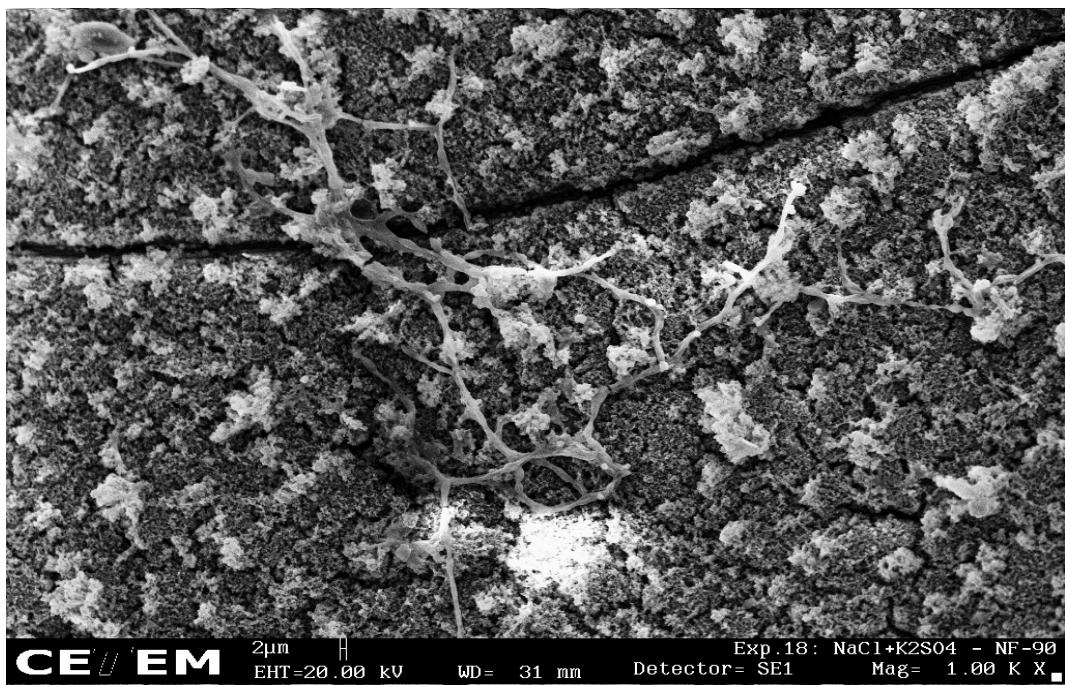


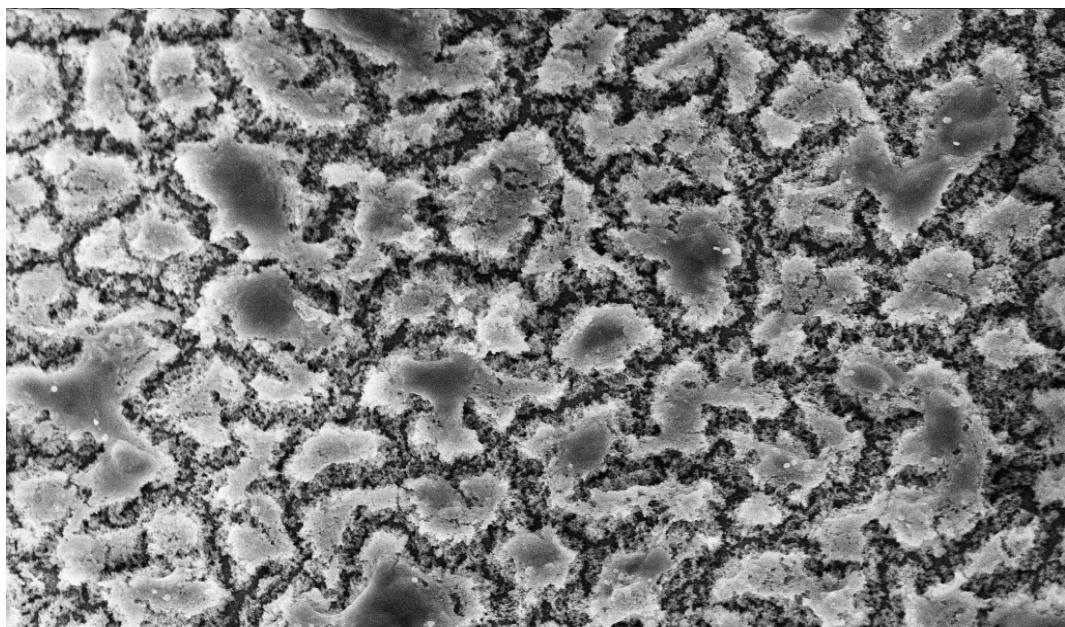


**CE / EM** 200nm H EHT=20.00 kV WD= 31 mm Detector= SE1 Exp.17: NaCl+Na<sub>2</sub>SO<sub>4</sub> - NF-90 Mag= 10.00 K X ■

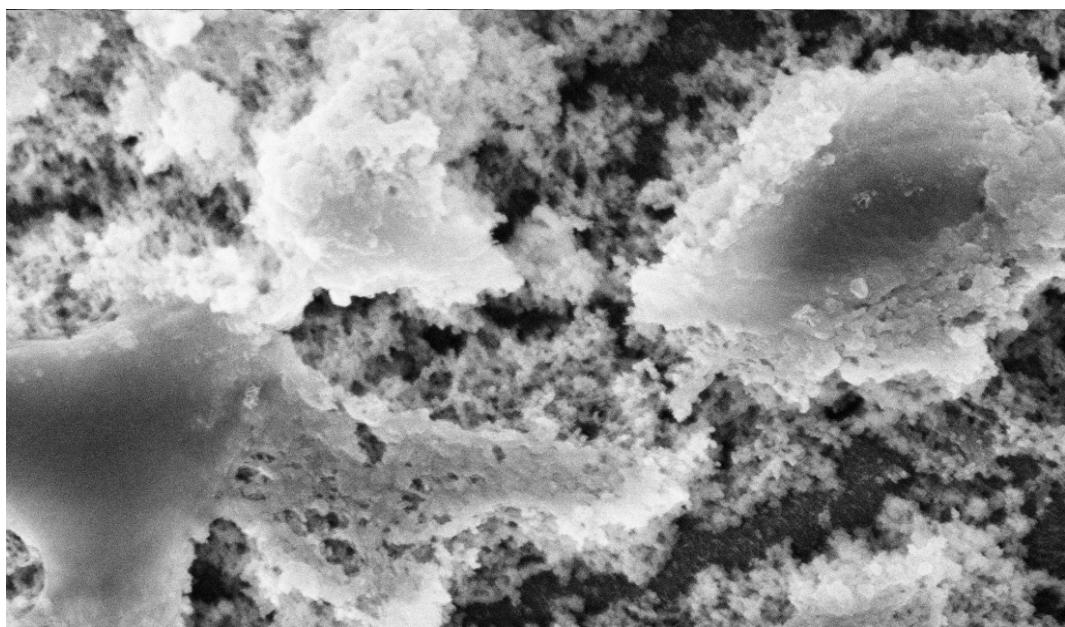


**CE / EM** 20μm H EHT=20.00 kV WD= 31 mm Detector= SE1 Exp.18: NaCl+K<sub>2</sub>SO<sub>4</sub> - NF-90 Mag= 100 X ■

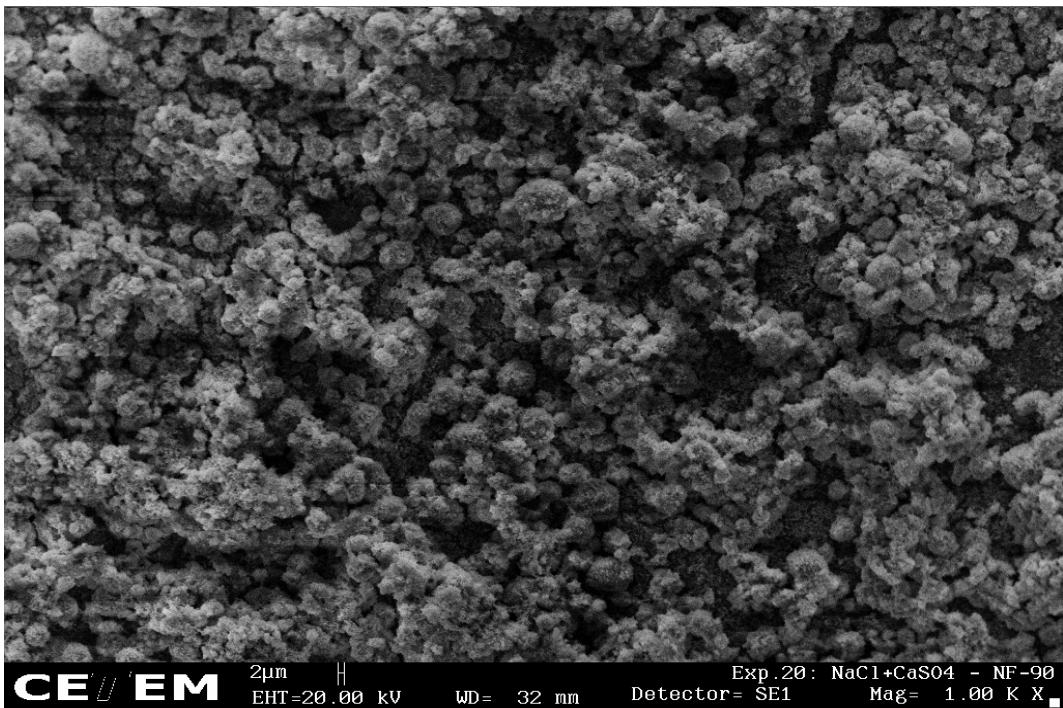
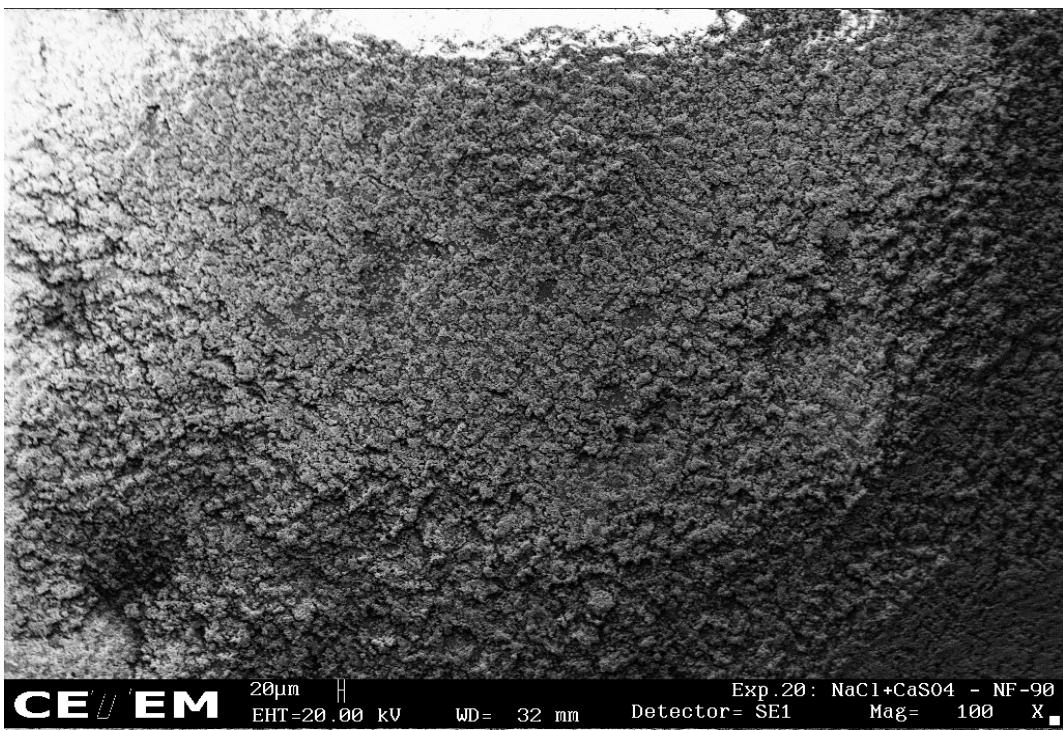


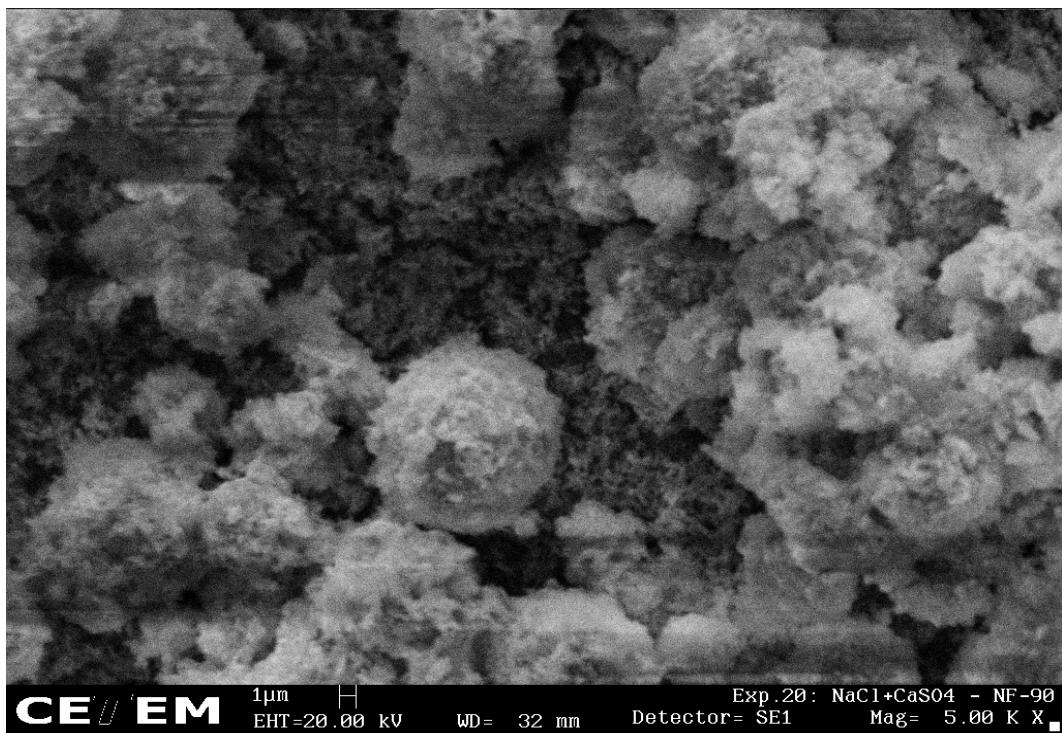


**CE / EM** 2 $\mu$ m H  
EHT=20.00 kV WD= 32 mm Detector= SE1 Exp.19: NaCl+MgSO<sub>4</sub> - NF-90  
Mag= 1.00 K X ■

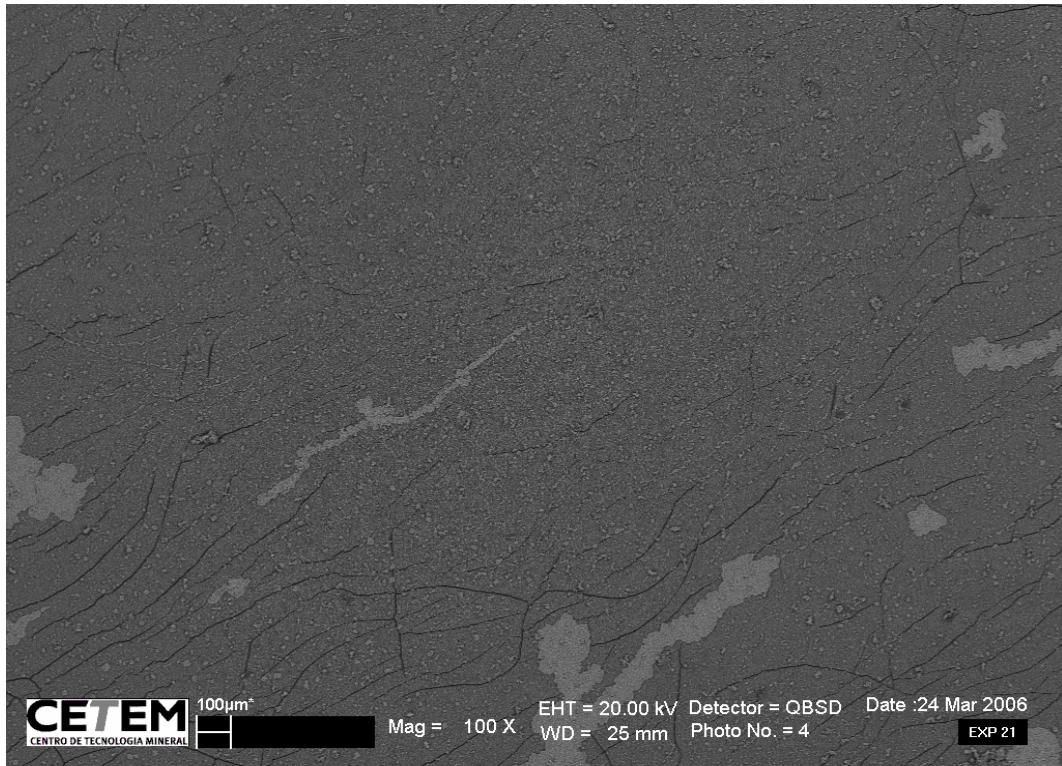


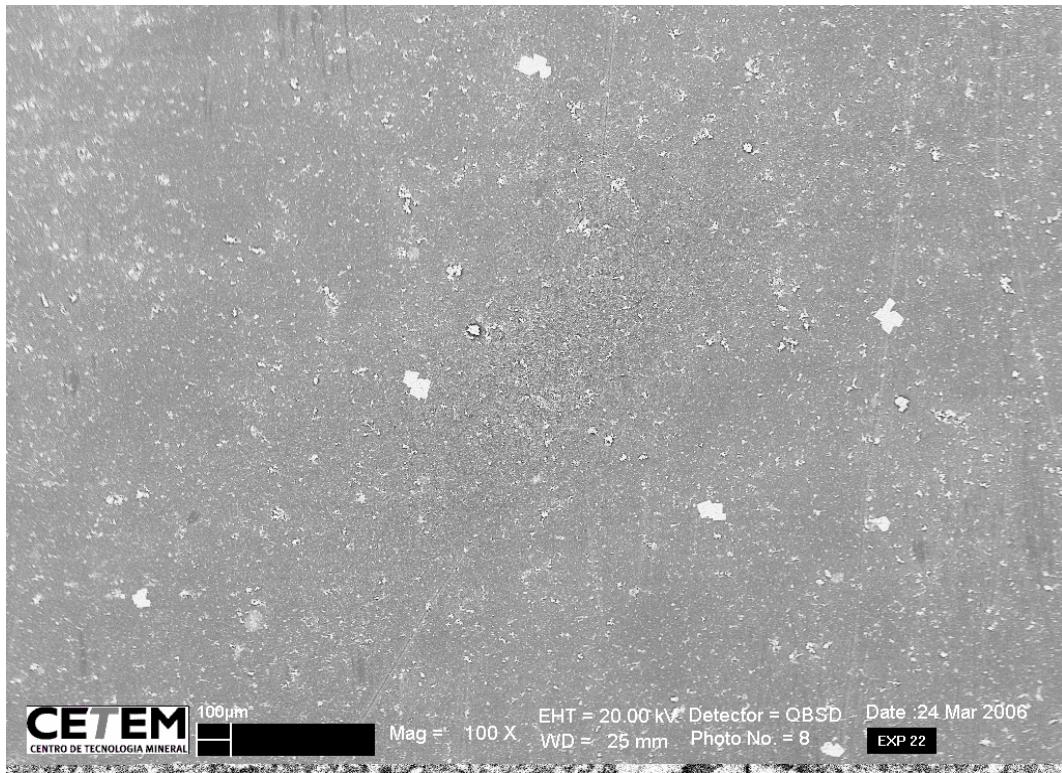
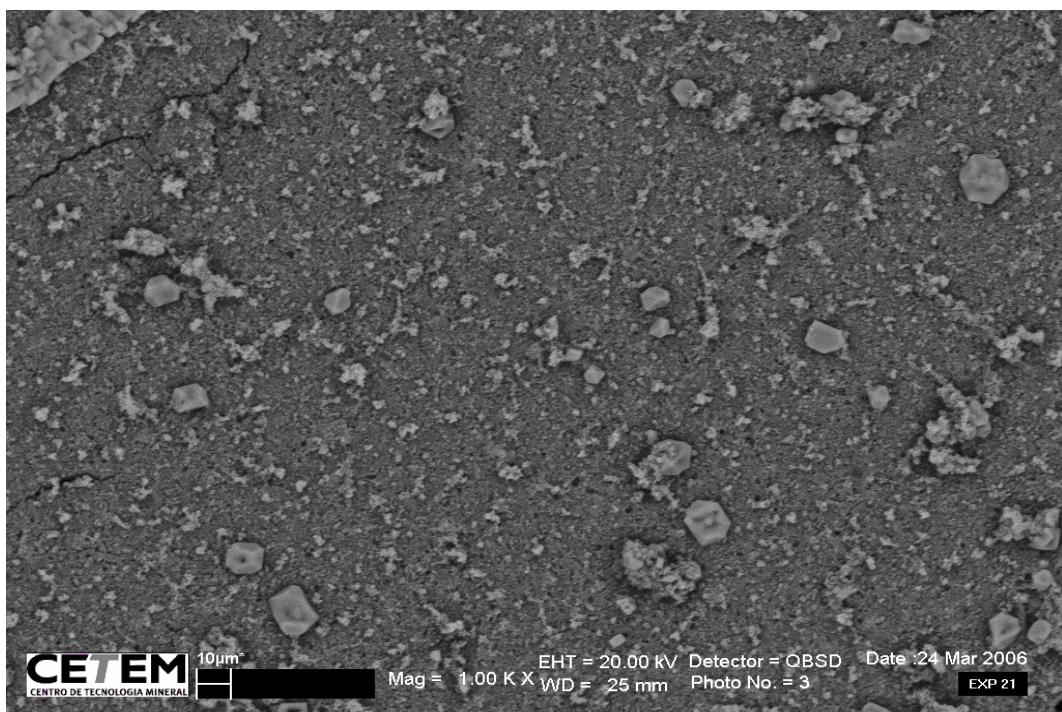
**CE / EM** 1 $\mu$ m H  
EHT=20.00 kV WD= 32 mm Detector= SE1 Exp.19: NaCl+MgSO<sub>4</sub> - NF-90  
Mag= 5.00 K X ■

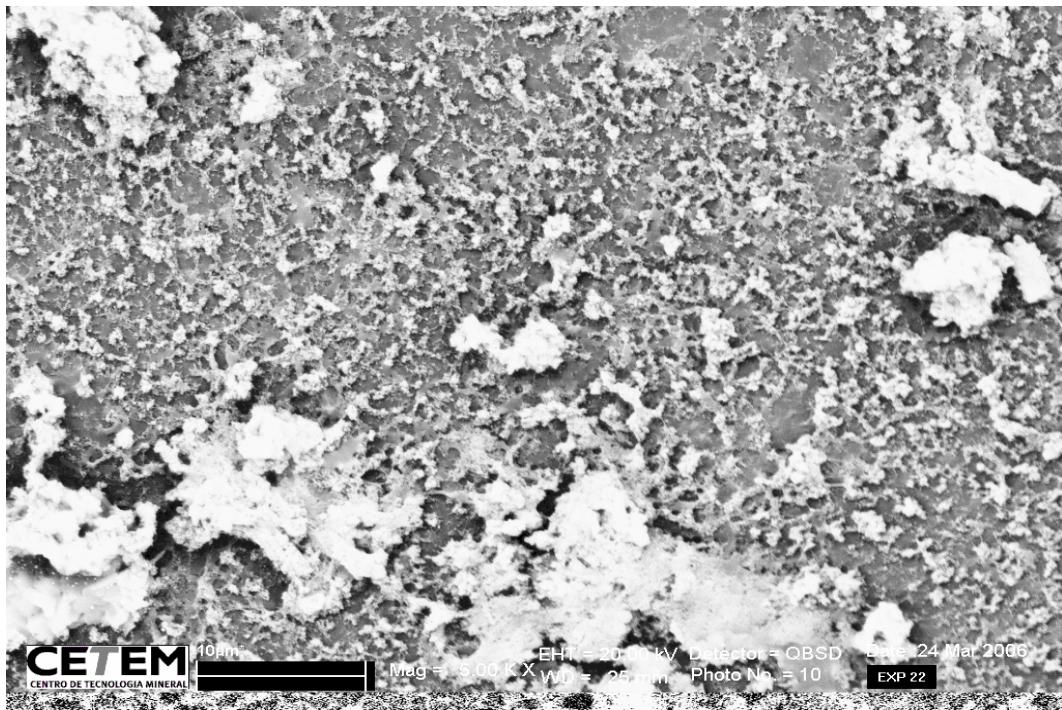
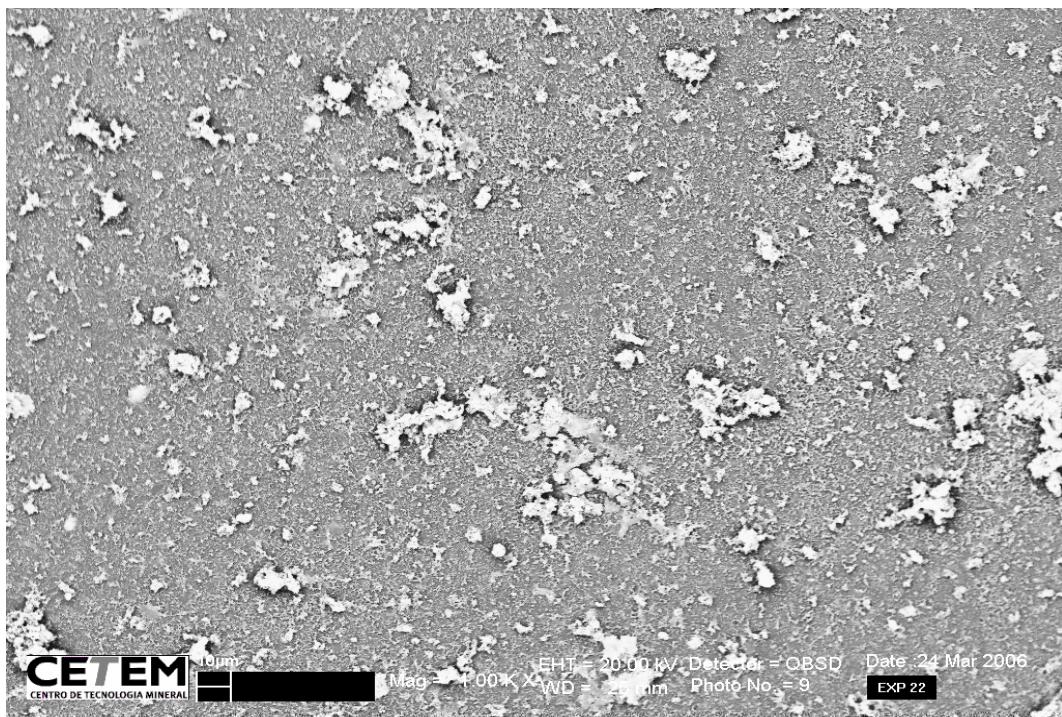


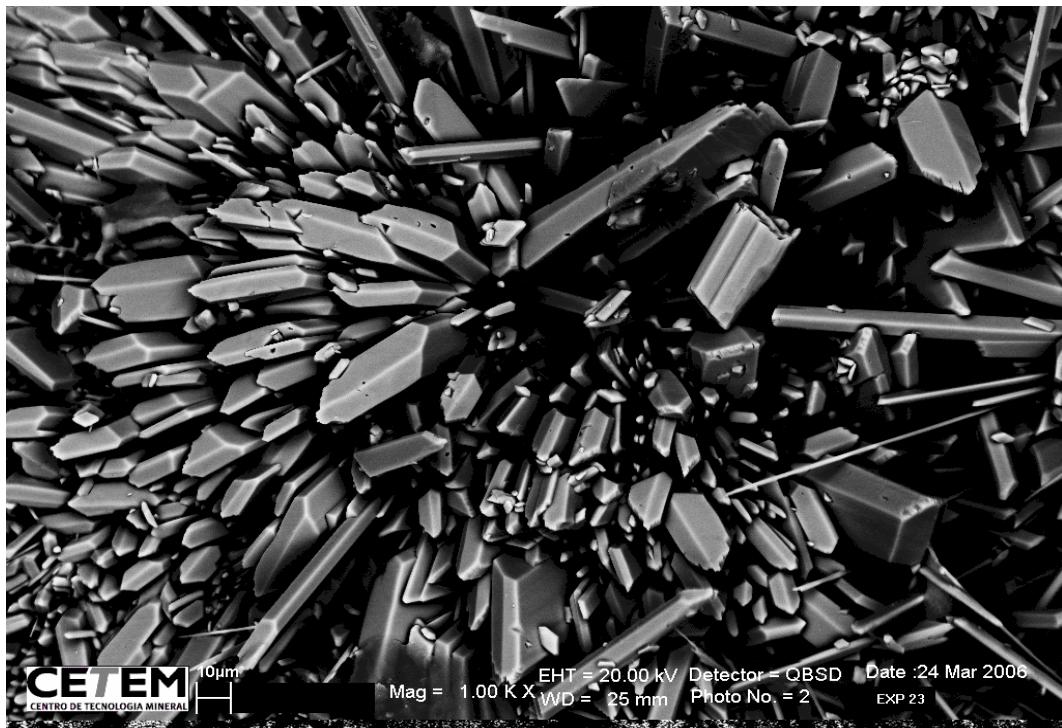
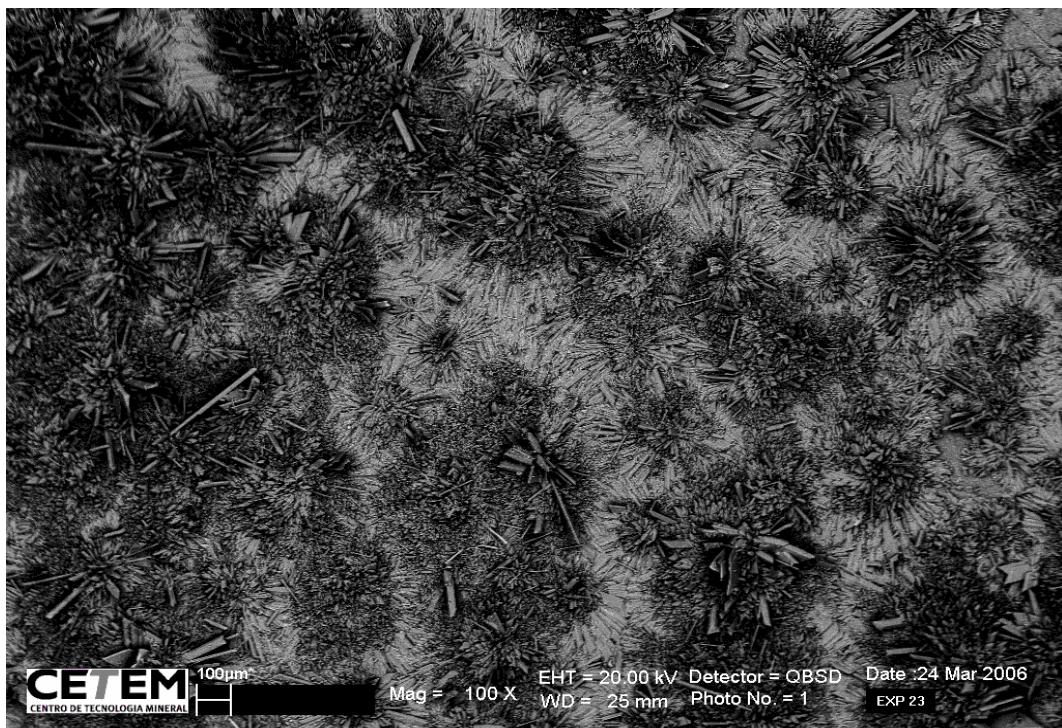


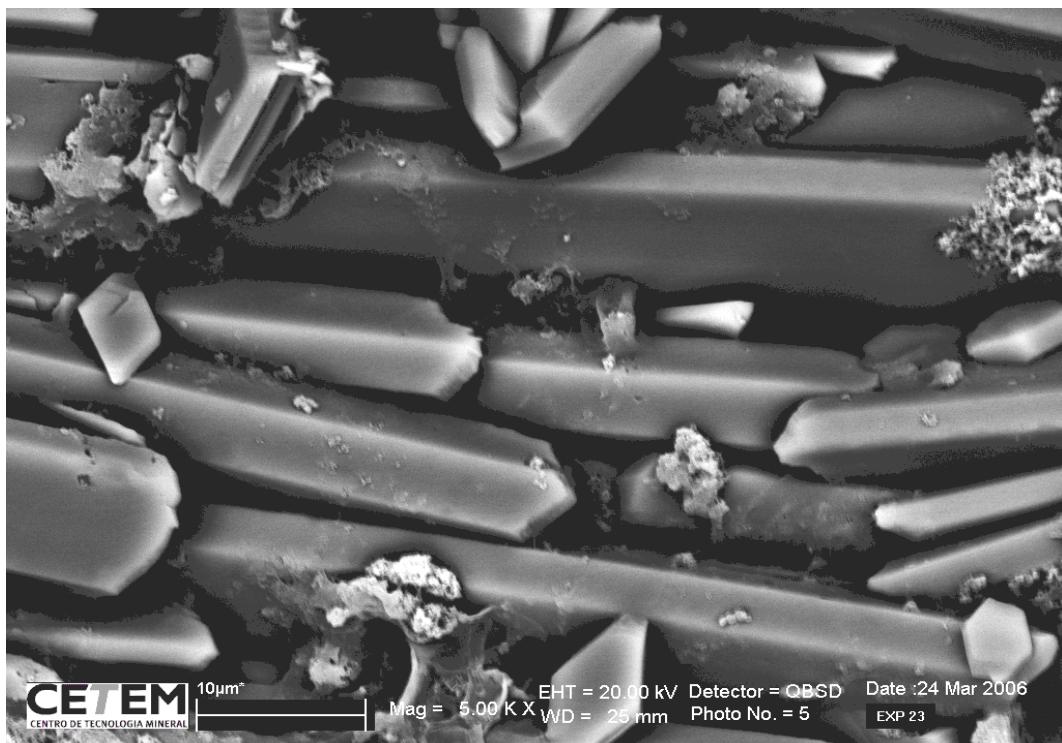
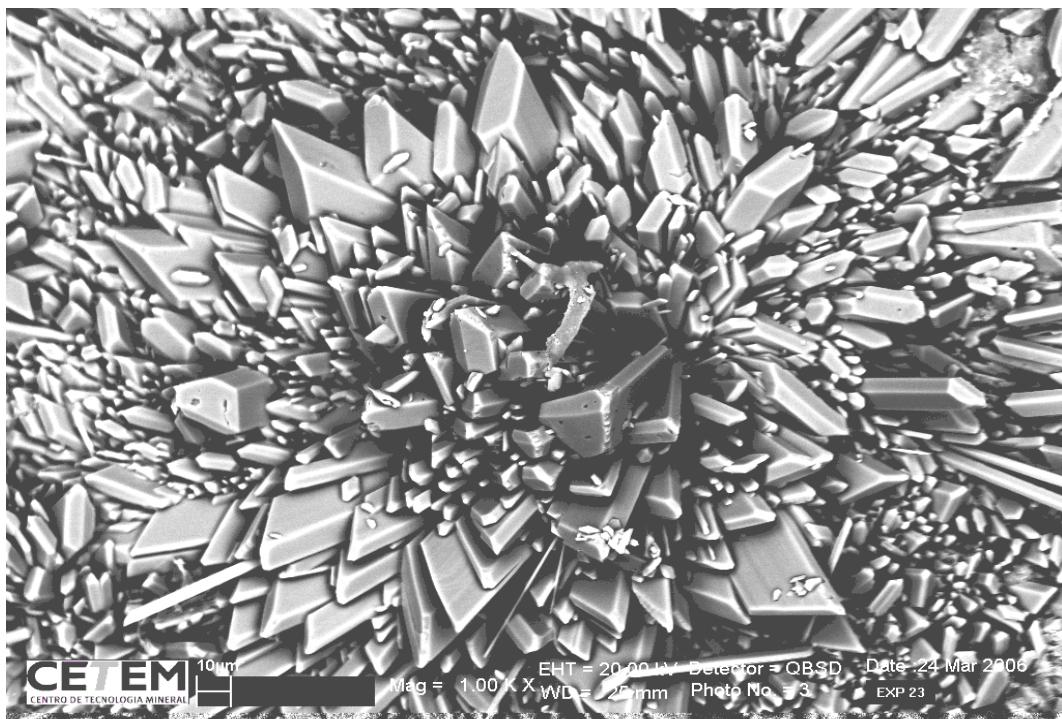
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# **ANEXO V**

## ANEXO V

### Parâmetros de análise do processo de Nanofiltração

parâmetro	fórmula	unidades
<b>rejeição</b>	$R=1-C_p/C_f$	
<b>recuperação ou conversão</b>	$C=C_p/Q_f$	
<b>velocidade de fluxo cruzado</b>	$V_{cf}=Q_f/A$	m/s
<b>vazão</b>	$Q$	$m^3/s$ ou $L/h$ ou gpd
<b>fluxo permeado</b>	$J=Q/A_m$	$kg/m^2.s$ ou $L/m^2.h$ ou gfd
<b>permeabilidade</b>	$L_p$	
<b>fator de concentração</b>	$c_f=C_c/C_f$	
<b>área perpendicular ao fluxo</b>	$A_p=c.h$	$m^2$
<b>fluxo solvente permeado</b>	$J_s=L_p.(dP-dp_i)$	
<b>fluxo soluto permeado</b>	$J_i=B.dC_i$	
<b>rejeição aparente ou observada</b>	$R_{obs} = (C_f - C_p)/C_f$	
<b>rejeição verdadeira</b>	$R_t = (C_m - C_p)/C_m$	
<b>concentração na membrana</b>	$C_m =$	
<b>coeficiente de transferência de massa(k)</b>	$\exp(J_s/k) = (C_m - C_p)/(C_f - C_p)$	
<b>número de Sherwood</b>	$Sh = k.dh/D$	$D$ =coeficiente de difusão
<b>número de Schmit</b>	$Sc = u/p.D$	
<b>número de Reynolds</b>	$Re = p.v.dh/u$	
<b>densidade</b>	$\rho$	$kg/m^3$
<b>viscosidade</b>	$\mu$	$Pa.s$
<b>diâmetro hidráulico</b>	$dh = 2.A_p/(c+h) \sim 2.h$	$Pa.s$
<b>supersaturação</b>	$ss = C_m/s = CP.C_f/s$	
<b>módulo de polarização de concentração</b>	$CP = (C_m - C_p)/(C_f - C_p) = \exp(J_s/k)$	

**Abreviaturas:**

C<sub>p</sub> = concentração do soluto permeado  
C<sub>f</sub> = concentração do soluto alimentação  
C<sub>c</sub> = concentração do soluto concentrado  
C<sub>m</sub> = concentração do soluto na membrana  
Q<sub>f</sub> = vazão de alimentação  
Q<sub>p</sub> = vazão de permeado  
A<sub>p</sub> = área perpendicular ao fluxo  
c = largura do canal de alimentação  
h = altura do canal de alimentação  
A<sub>m</sub> = área de membrana  
d<sub>pi</sub> = pressão osmótica  
J<sub>s</sub> = fluxo do solvente  
J<sub>i</sub> = fluxo de soluto  
s = solubilidade

**bibliografia:**

Keith Scott; Handbook of Industrial Membranes; 1995; Elsevier Science Publishers.

W.J. Koros, Y.H. Ma, T. Shimidzu; Terminology for Membranes and Membrane Processes-IUPAC; Journal of Membrane Science 120 (1996) 149-159.

Membrane technology

Desalination

Journal of membrane science

**Análise Teórica da solubilidade de sais inorgânicos**  
**Incrustantes**

<b>Composto</b>	<b>Água Marinha (mg/L)</b>	<b>Kps (mol/L) 20°C</b>	<b>solubilidade (mg/L)</b>
NaCl	27210		360000
MgCl <sub>2</sub>	3800		542500
MgSO <sub>4</sub>	1650		445000
<b>CaSO<sub>4</sub>(.2H<sub>2</sub>O)</b>	1260	6,1*10-5	<b>2090</b>
K <sub>2</sub> SO <sub>4</sub>	860		120000
<b>BaSO<sub>4</sub></b>	~		<b>2,4</b>
Na <sub>2</sub> SO <sub>4</sub>	~		194000
<b>SrSO<sub>4</sub></b>	~	2,81*10-7	<b>140</b>
CaCl <sub>2</sub>	~		745000
SrCl <sub>2</sub>	~		529000
<b>Ionte</b>	<b>Água Marinha (mg/L)</b>	<b>meq/L</b>	<b>1meq/L (mg/L)</b>
Cl	19353	545,924	35,45
Na	10800	469,565	23
SO <sub>4</sub>	2724	56,750	48
Mg	1600	131,148	12,2
Ca	416	20,800	20
K	390	10,000	39
HCO <sub>3</sub>	153	2,508	61
Br	68	0,850	80
Sr	15	0,342	43,8
Si (4)	4,9	0,700	7
CO <sub>3</sub>	2,3	0,077	30
F	1,7	0,089	19
Ba	0,05	0,001	68,7
<b>TDS</b>	<b>35527,95</b>		
<b>pH</b>	<b>8,2</b>		

Siedell; Solubilities of Inorganic and Metal Organic Compounds

## **Preparação da água do mar sintética**

Em função da diversidade de métodos encontrados na literatura para preparação da água do mar sintética e visando a minimização de erros e a reproduzibilidade dos experimentos a solução foi preparada segundo a norma ASTM D1141.

De acordo com a norma: para preparar 10 L de solução sintética de água do mar é necessário dissolver 245,34 g de cloreto de sódio e 40,94 g de sulfato de sódio anidro em aproximadamente 8 L de água (com condutividade baixa de acordo com a norma D1193). Adicionar 200 mL de solução estoque nº 1 e devagar e com agitação vigorosa. Em seguida adicionar 100 mL de solução estoque nº 2, completar o volume até 10 L. Ajustar o pH para 8,2 com NaOH 0,1N se necessário.

*Solução estoque nº 1:* Dissolver a quantidade indicada dos sais em 7 L de água e estocar em recipiente fechado.

MgCl <sub>2</sub> .6H <sub>2</sub> O	3889,0 g (=555,6g/L)
CaCl <sub>2</sub> (anidro)	405,6 g (=57,9 g/L)
SrCl <sub>2</sub> 6H <sub>2</sub> O	14,8 g (= 2,1g/L)

*Solução estoque nº 2:* Dissolver a quantidade indicada dos sais em 7 L de água e estocar em recipiente fechado.

KCl	486,2 g (=69,5 g/L)
NaHCO <sub>3</sub>	140,7 g (=20,1 g/L)
KBr	70,4 g (=10,0 g/L)
H <sub>3</sub> BO <sub>3</sub>	19,0 g (=2,7 g/L)
NaF	2,1 g (=0,3 g/L)